LEVEL II

(13)

AD A109053

CONTRACT DAAK 70-79-C-0046

FINAL REPORT

DEVELOPMENT OF PRECOAT FILTRATION TECHNOLOGY FOR REVERSE OSMOSIS UNITS

Submitted by:

JOHNS-MANVILLE SALES CORPORATION
RESEARCH AND DEVELOPMENT CENTER
Ken-Caryl Ranch
Denver, Colorado 80217

November 20, 1981

G R Bell /s
G. R. Bell, Project Manager

G. Robles /s
G. Robles, Principal Investigator

TABLE OF CONTENTS

SUMMARY

This project was undertaken to determine whether diatomaceous earth filter aid (DE) filtration would be an effective alternative for the presently specified multi-media filter on the 600 GPH ROWPU. The project included both filtration studies and small scale reverse osmosis membrane fouling tests for several types of water sources.

Data from six different water sources, two bench studies and four field studies, demonstrated that DE can easily meet, and if necessary exceed, the criteria set by the Army for multi-media filtered water for RO feed. For most tests a filter aid prepared by coating CELITE 503R with aluminum hydrate had the best balance between filtered water quality and cycle length. Such a filter aid could be purchased ready mixed greatly simplifying operation.

Three RO "life" tests were attempted. One was aborted after the membrane was damaged by chlorine from an extraneous source. The other two were successfully completed without evidence of particulate fouling of the membranes.

Cost of filter aid, the principle cost variable, is discussed in some detail. Depending on water source characteristics, it is estimated that filter aid would cost between four cents and fifty-five cents per 1,000 gallons filtered. The latter is for a source containing 2,500 mg/l total suspended solids.

Initial studies indicate that DE equipment is available which will fit into the space occupied by the multi-media filter and accessories. More detailed engineering is recommended.

Technology only available after the project was initiated indicates that both improved filtered water quality and decreased DE consumption might be possible through the use of certain polymers with DE. Authorization of more work along these lines is also recommended.

OBJECTIVES

This program was undertaken to determine whether diatomaceous earth filter aid (DE) filtration could provide a functionally alternative, cost effective means for adequately clarifying various water sources for subsequent reverse-osmosis (RO) treatment for field troop use. On the 600 GPH ROWPU a single multi-media filter is currently specified.

In this study DE filtration objectives divided into three categories:

1. Determine the ability of DE to provide adequately clarified water for RO feed. As currently specified, this is an unchlorinated or dechlorinated filtered product having a turbidity of less than 1.0 NTU and no particles larger than 5 um.

2. Establish that DE equipment required to produce 1,800 gph of such water, assuming one-third RO product recovery, will fit into the space

presently specified for the multi-media filter and accessories in the 600 GPH ROWPU.

3. Establish a range of estimates for the equipment and operating costs for DE for the 600 GPH ROWPU.

As noted earlier, multi-media filtration with in-line feed of a cationic polymer to the influent is currently specified as the means for such clarificaion. For field operations multi-media filters have the apparent advantage of simplicity and compactness of the equipment train; but these filters also have some important disadvantages for such service:

1. The multi-media filter itself is relatively heavy, a disadvantage for airborne operations, and more particularly, for larger sized ROWPU assemblies with dual filters.

2. In an air drop if a unit does not land upright the media are "scrambled" and not available for service until a source of water is available to reclassify the bed, assuming the under drainage

system is intact. Otherwise, the media must be re-stacked.

3. Determination of the proper amount of the single polymer feed for different water sources may be beyond the capabilities of field troops. Also on certain water sources the polymer will not be effective, e.g., removal of soluble Fe from some surface and well-point supplies and for algae removal from surface sources.

4. Net filtered water output of multi-media filters is determined by a balance between the "dirt holding" capacity of the media and backwash water volume requirements. The proposed use of unfiltered water for backwashing, while feasible with relatively clear sources, will not be feasible with muddy surface supplies. As a result, as filtering cycle length decreases, backwash requirements with part of the filtered product are disproportionately increased to a point where there may be no net output of filtered water available for use.

DE filtration, because it has a fundamentally different technology, is not subject to these same problems and limitations. Further, DE filtration in conjunction with the ERDLATOR has been used to supply potable water for field operations for almost 40 years. Thus, the DE filter aid concept is not a new, untried technology to the ARMY. What is new is that modern field operations may have to deal with different and more difficult types of contamination, e.g., bacterial, chemical or radiological agents, which could be beyond the capability of the ERDLATOR-DE filter systems to remove.

In this concept, the RO unit is now regarded as a backup for the primary clarification or purification unit, which must be able to provide potable quality water except where the special capabilities of RO are required. This represented some change in philosophy in the course of the project, which initially was concerned only with preparation of RO feed. The advantage of the change, of course, is that about three times as much potable water is available if RO is not required. There also are less stringent finished water requirements since more relaxed clarity standards are specified if the filtered water is

not to be subjected to further RO treatment in which membrane fouling would be a problem. For the purposes of this study, it was planned that all filtered water would have to meet the RO feed quality requirements.

In addition, while not specified for these ROWPU feedwaters, the plugging index, plugging factor or silt density index (all of which are generated from the same set of data) are used by the RO membrane suppliers as a more sophisticated measure of feedwater fouling characteristics. Details of the test procedure are included in Appendix I. A maximum 30 psi, 0.45 um 15 minute plugging index (PI_{15}) value of 45 is specified by some manufacturers as adequate quality for RO feed. To provide a linkage between this work and other work in the RO field, where feasible, data on PI values for feed and filtered water quality were obtained. At some test sites, notably the brackish water site at Ft. Eustis, Virginia, corrosion of the test equipment prevented collection of meaningful PI data.

TEST PROGRAM AND TEST RESULTS

Test Program

Test Sites - As originally planned, the program consisted of two phases: (1) a bench scale study at the contractor's R&D facilities in Denver, Colorado and (2) field tests at four selected sites covering a variety of differing water sources.

The bench study was planned to select the appropriate grade or grades of DE and filtration rates when a standard turbidity source, ASP400 clay, was used in "city" water. Results from this study were then to be used as guides in the subsequent field tests, thereby reducing the amount of experimentation at each test site.

At each of the four field test sites two tasks were planned. A preliminary study would be made by contractor personnel to establish a best mode for DE filter operation. Then the filter equipment would be operated by MERADCOM personnel, under contractor supervision, to supply an RO module for 500 hours. A new module was to be supplied for each test site.

After completing Task 1 at the first test site, which was MERADCOM at Ft. Belvoir, Virginia, the program was changed so that the contractor would furnish and operate the RO module through the 500 hour test periods. Delays during the contract modification process precluded the making of the 500 hour test at Ft. Belvoir. At Ft. Detrick, Maryland, the 500 hour test was abandoned after about 200 hours because the DE filtered water was found to be contaminated periodically with free Cl_2, causing irreversible damage to the RO membrane. The 500 hour tests were successfully completed at the two final field test sites.

Selection of the three test sites (other than Ft. Belvoir) after the contract modification, became the reponsibility of the contractor with the advice and consent of MERADCOM personnel. The three sites chosen and some characteristics of each were:

1. Ft. Detrick, Maryland water treatment plant. This plant is on a rather flashy river with wide ranges in flow and turbidity levels. Field operations would be expected to encounter and have to deal with such sources.

2. Ft. Eustis, Virginia. This test site is on a brackish water estuary adjacent to the sewage treatment plant. Observed salinity at the start of the test period was about 15,000 umhos due to prolonged dry weather and varied down to about 9,000 umhos after sustained rainfall. RO did effectively reduce salinity below levels necessary for field troop use.

3. Castle Rock, Colorado Well Number 7. This soluble iron-bearing supply was selected as an alternate to Ft. Devons, Massachusetts, after it was found that the latter uses down-well prechlorination to control bacterial growths. Soluble iron is common in many parts of the country and especially in shallow wells or well points, and in some surface supplies. Despite assurances of some RO membrane suppliers that iron is not a serious foulant, PI values and visual observations indicate that it would be.

Early termination of the tests at Ft. Detrick resulted in too few data from high turbidity tests to reliably

assess the performance of the DE process. Since high turbidity sources would appear to be one of the problem areas for multi-media filters, a final bench scale test with higher turbidity was added to the program after the fourth test site. Time and funds available limited this test to DE filtration without subsequent RO treatment.

Test Procedure - Filter Operation - The filtration method used for this project was DE precoat filtration. In this process, slurry of filter aid and water is pumped through a filter septum forming a thin precoat on the screen. During filtration, a small amount of filter aid is continuously added to the influent as bodyfeed. The septum, which is mounted vertically on the filter, is a 9.6 inch diameter double sided disc with a cover of 24 x 110 mesh Dutch weave stainless steel screen. The amount of precoat placed on the one square foot filter is typically 0.15 pounds of filter aid per square foot of filtering area. The body feed is prepared in a separate tank, and the feed rate is dependent upon the quality of the water to be filtered.

A typical flow scheme of the filter operation follows: First, the raw water was pumped to a raw water surge tank. From this tank it was transferred to a conditioning tank at a rate of 1.2 gpm. At the conditioning tank the body feed was added and mixed with an agitator. A Moyno pump then fed the conditioned water to the filter. Filtration rate was one gallon per minute per square foot of filtering area (gsfm). After filtering, the filtrate was collected for processing through the RO unit. Filtration cycle length was monitored by a controller which recorded pressure versus time. The controller also stopped the filter cycle at a set pressure differential of 35 psi and simultaneously stopped the RO unit.

Filter Aids Used - A relatively wide range of DE filter aid properties was used as shown in Table 1. Most of these were used in the initial bench scale studies, and in addition to these commercially available "grades", one or two special materials were tried. The latter proved to have no special merit and were dropped. Field test work was largely confined Hyflo Super-Cel and Celite 503.

TABLE 1

CELITE FILTER AIDS

Filter Aid	Relative Water Permeability	Median Pore Size
Filter-Cel	0.22	1.0 um
Standard Super-Cel	0.45	3.2 - 4.0 um
Celite 512	0.65	5.0 um
Hyflo Super-Cel	1.00	6.5 - 7.5 um
Celite 503	1.80	10.0 um

Test Equipment -The same type of DE test equipment was used for all tasks and test sites. When the program was delayed it became necessary to substitute a different filter and accessories to complete the program, but this filter was made from the same plans and functioned in an identical way to that originally used. Photographs of the vertical leaf filter are included in Figures 1, 2 and 3.

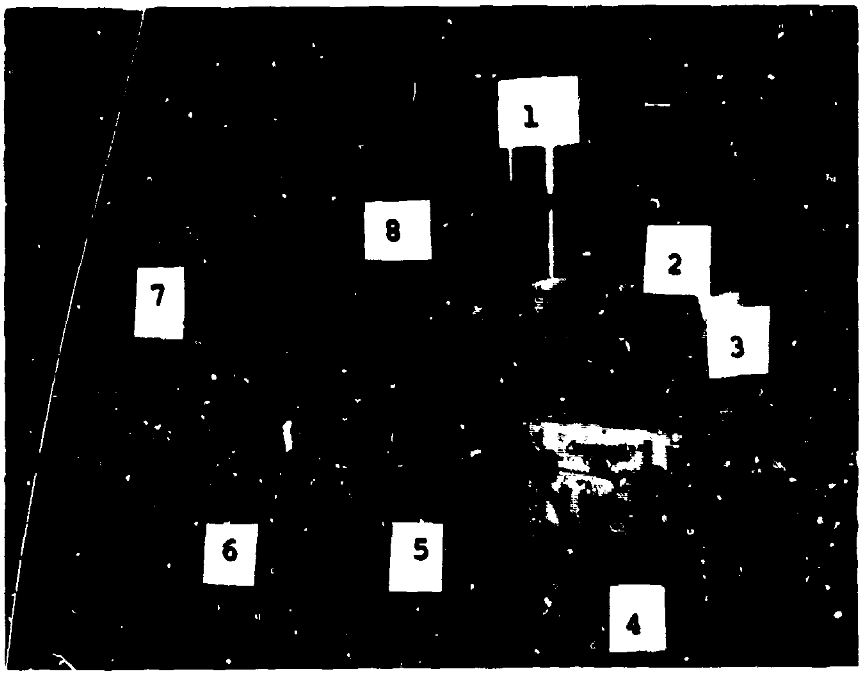


Figure 1. Overall view of the one square foot pressure leaf filter system.

No. 1 - Standard Turbidity Tank
No. 2 - One Square Foot Filter
No. 3 - Filtrate Tank
No. 4 - Precoat Tank
No. 5 - Body Feed Pump
No. 6 - Body Feed Tank
No. 7 - Pressure Controller and Recorder
No. 8 - Conditioning Tank

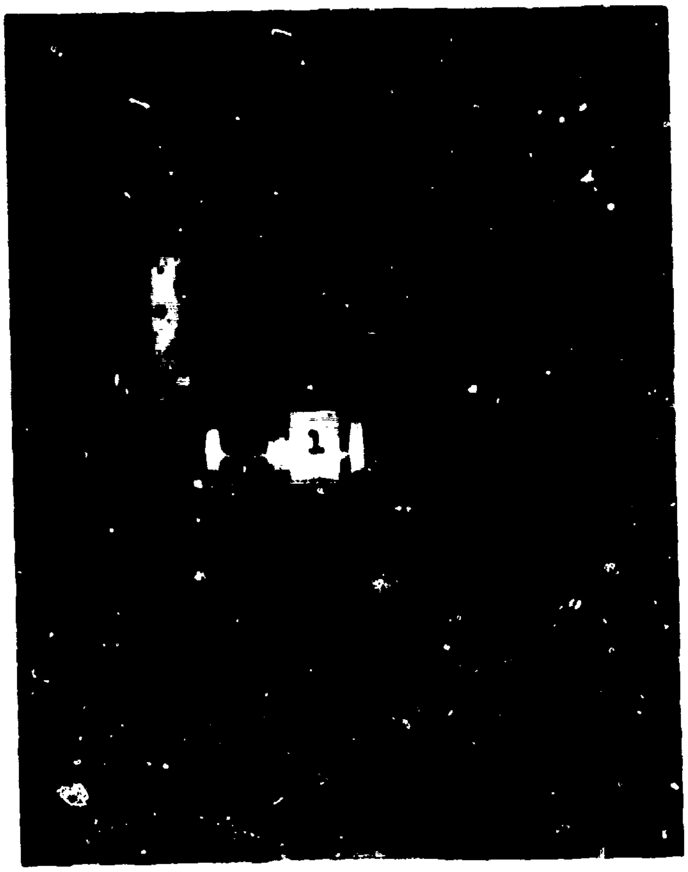


Figure 2. Close up of the one square foot filter and the filter leaf.

No. 1 - One square foot filter leaf with a 24 x 110 mesh Dutch weave stainless steel septum on each side.

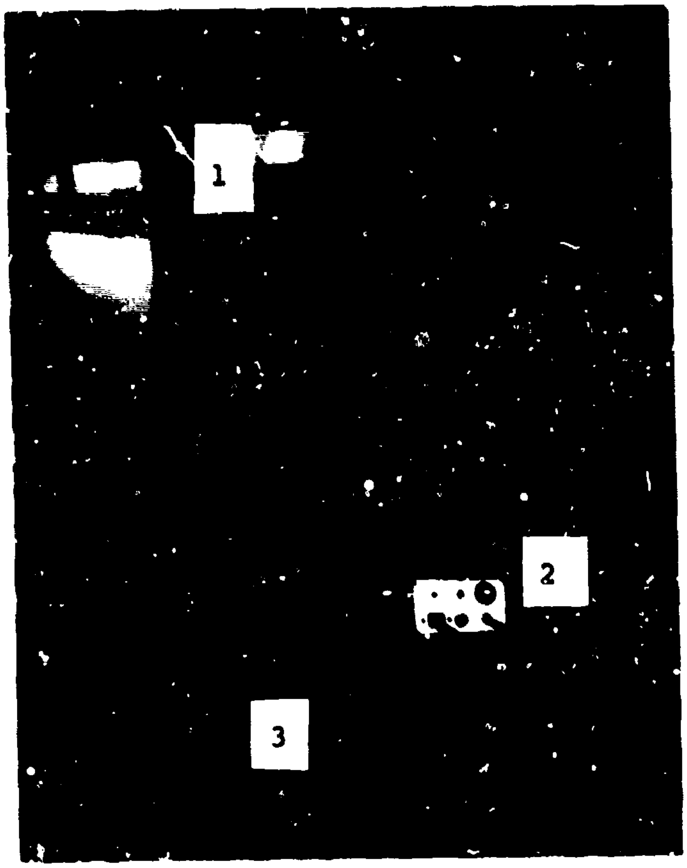


Figure 3. Close up view of conditioning tank and body feed system.

No. 1 - Conditioning Tank and Agitator
No. 2 - Body Feed Pump or Polymer Feed Pump
No. 3 - Body Feed or Polymer Tank

__RO System__ - As a result of misunderstandings relating to sizing of RO components, a single module RO system was constructed in which a TFC^R Model 4600 PA brackish water element and its housing was used. This module proved to be much too large for the volume of DE filtered water available from the pilot filter system. Consultation with Fluid Systems Division of UOP, Inc. resulted in a substitution of a TFC Model 7005 PA element and housing. Even this module should have a somewhat higher total flow than 0.75 to 1.0 gpm but Fluid Systems technical people advised that for this single element assembly, valid results would be obtained. The primary interest was whether the elements or modules would become fouled.

The RO system consisted of a transfer pump from DE filtered water storage through a parallel pair of 5 um cartridge filters to the suction of the RO feed pump, which was a Model 280 Cat pump. An adjustable relief valve between the pump and RO module provided overpressure protection and an identical valve downstream of the module controlled back pressure as measured by a gage just upstream. Pressure into the module was measured by an

identical gage so that drop across the module could be determined by difference.

Flow through the module was controlled by a combination of back pressure and the motor speed driving the Cat pump. Almost any total flow and "split" between permeate and concentrate could be maintained. Photographs of the RO unit are presented in Figures 4, 5 and 6.

Performance of the DE and RO systems was monitored by periodic pressure differential and flow rate readings. For the DE system, records of feed and filtered water turbidities (Hach) were maintained and PI values were determined, except at Ft. Eustis as explained earlier.

For the RO unit, in addition to drive pressure and drop through the module, the split between concentrate and permeate flows was recorded. Resistivity or salinity of these streams was also determined and recorded.

Test Results

General - This section is divided into six subsections covering the initial bench work at Denver (Phase I), each of the four field test sites, and the final

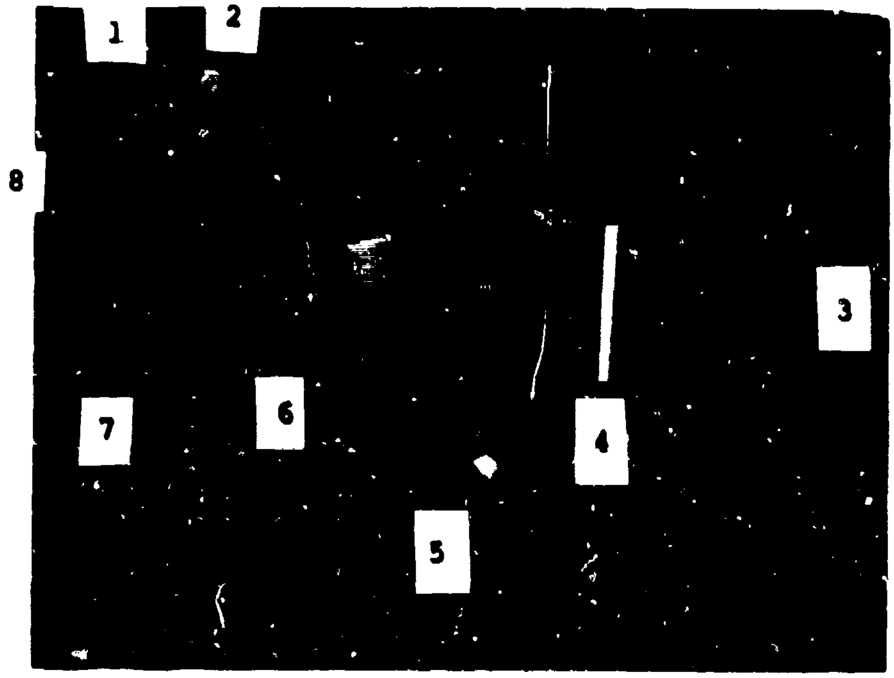


Figure 4. Overall view of reverse osmosis unit.

No. 1 - Back Pressure Relief Valve
No. 2 - Back Pressure Gauge
No. 3 - Cartridge Filter (one of two)
No. 4 - Water Meter
No. 5 - Water Inlet
No. 6 - High Pressure Pump Control
No. 7 - Permeate Outlet
No. 8 - Concentrate Outlet

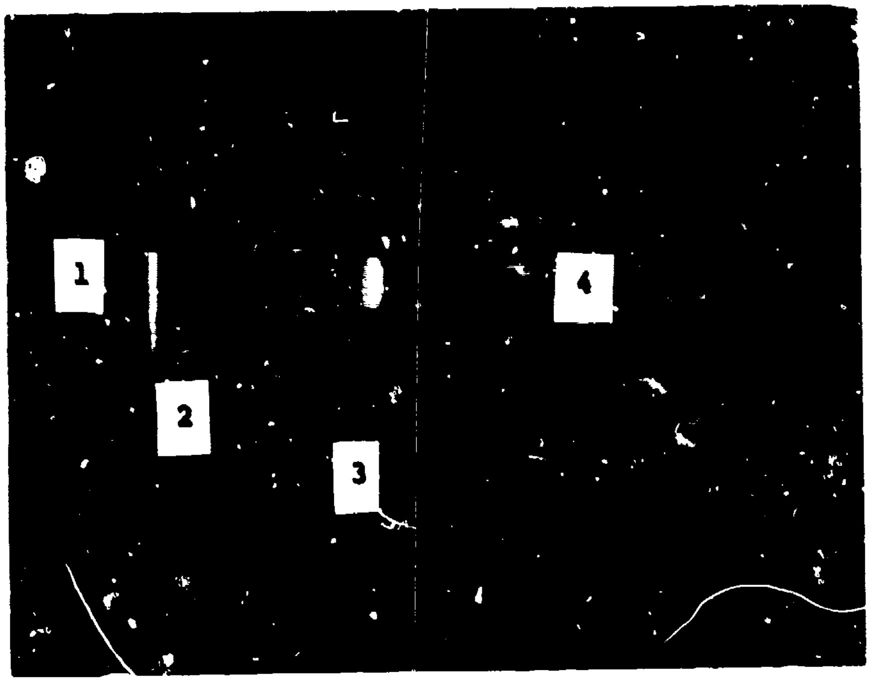


Figure 5. Close-up View of Reverse Osmosis Unit showing high pressure pump and pressure tube.

No. 1 - Drive Pressure Relief Valve
No. 2 - Drive Pressure Gauge
No. 3 - Cat Model - High Pressure Pump
No. 4 - Spiral-Wound Reverse Osmosis Housing

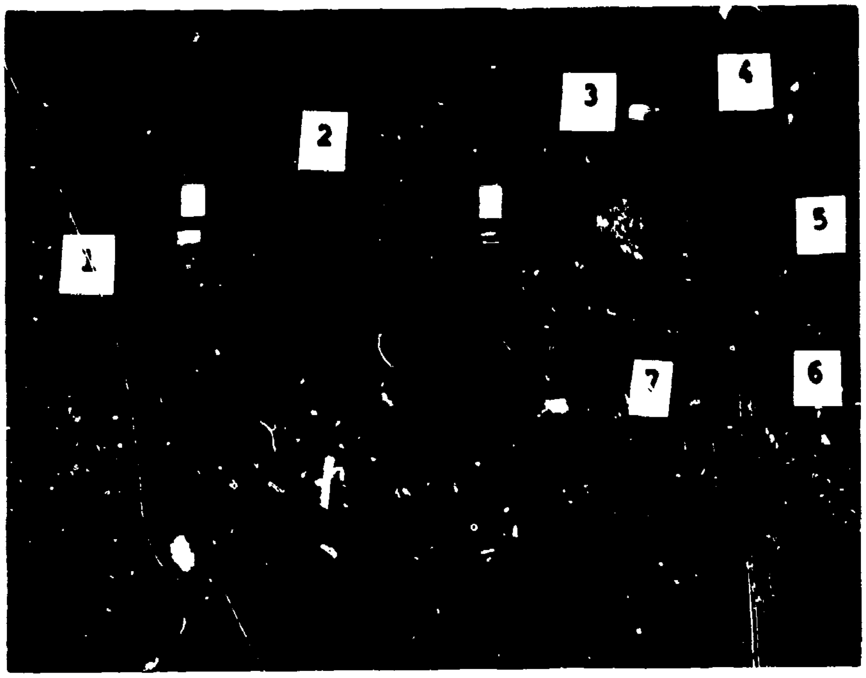


Figure 6. Close up view of spiral wound reverse osmosis housing.

No. 1 - Drive Pressure Relief Valve
No. 2 - Spiral-Wound Reverse Osmosis Element Housing
No. 3 - Back Pressure Gauge
No. 4 - Back Pressure Relief Valve
No. 5 - Concentrate Stream
No. 6 - Permeate Stream
No. 7 - Cat Pump Controller

high turbidity study at Denver. Each subsection includes a brief description of modifications to the test setup for the specific site, and presentation of the resulting data in tabular form with a summation of the findings which resulted.

Phase I - Bench Tests, Denver, Colorado - This study used a suspension of ASP400 clay in Denver city water as the test medium. The objective was to attain filtered water PI_{15} values of 40 or less, although some RO membrane suppliers specify less than 45 as adequate to prevent membrane fouling. MERADCOM does not use any PI specification to define water quality, but at either of these PI levels turbidity is too low to be a significant measure of fouling tendency, and well below the MERADCOM limit of 1.0 NTU (Hach).

The one square foot vertical leaf filter was set up at the Johns-Manville R&D Center as shown in Figure 1. A 300 gallon feed tank was used to make up the standard test water. This test suspension was made by first slurrying 11.4 grams of ASP 400 in one liter of water. The feed tank was filled with 300 gallons of tap water (potable), the mixer started and the ASP 400 slurry added. This

represented a 10 ppm concentration of ASP 400. The last few tests were run with 20 ppm ASP 400.

In this study the character of the city water had as much, if not more, effect than the standard clay. The water supply came from one of the Denver Water Department's older sand filter plants and was observed to have a slight yellow-green color. This color was tentatively identified as organic in nature, and probably fairly large molecules, since they could be removed by a relatively fine grade of DE.

Prefiltration of this water established that there would be no difficulty in removing the ASP400, but special techniques were required for filtering the combination of unfiltered tap water plus ASP400.

Table 2 summarizes the results of the bench scale filtration studies. It includes data when unfiltered, chlorinated unfiltered and chlorinated prefiltered tap waters were used as the suspension media for the ASP 400. PI values are for fifteen minutes at 30 psi and are less than spectacular for unfiltered water suspensions using DE filter aids ranging from moderately to highly retentive.

Chlorination to about 8 to 10 mg/l, in case the color was due to some oxidizable Fe complex, did improve product quality, but prefiltration of the chlorinated tap water with Celite 512 produced better results. Even so it sometimes took an appreciable period of time to get down to targeted PI values. Values in the 28 to 30 range were attained.

Because double filtration would not be practical from a field operations standpoint, use of aluminum hydrate-coated DE was proposed for a single pass filtration. The coating process of U. S. Patent No. 3,233,741 could readily be accomplished in the field by

TABLE 2

INITIAL STUDIES WITH DENVER TAP WATER

Filter Feed	Filter Aid	Cycle Length Hours	Pressure Drop psi	Plugging Index	
				Initial	Final
Tap Water + ASP400	Celite 503	1.75	2	80	80
Same	Hyflo	2.0	2	80	80
Same	Filter-Cel	4.0	21	56	80
Tap Water (Alone)	Celite 512	2.5		80	35
Chlorinated Tap Water	Celite 512	1		28	24
Chlorinated Tap Water + ASP400	Celite 512	4.5		80	28
Celite 512 Filtered Chlor. Tap Water + ASP400	Celite 512	1		30	
Same	Hyflo	1		30	24

simply suspending premixed and packaged DE, alum and soda ash in water. However, individual components were used to form the coatings in these studies.

Table 3 summarizes the results of this group of tests. The influence of the tap water quality on PI values of the filtered product is still very evident, but with reasonable tap water quality acceptible PI values were attained. Conversely, with poor tap water quality, good initial PI values deteriorated as the filtering cycle progressed even when a special very fine coated DE was tried.

Returning to the assumption that the poor filtering characteristics of the tap water were due to some organic material, a test was made using a mixture Hyflo and PAC*. The results, with a suspension made with relatively poor tap water, were very good. PI values on a continuing basis are shown in this tabulation:

* Westvaco 5A-15 powdered activated carbon.

TABLE 3

FILTRATION TEST RESULTS WHEN USING COATED FILTER AIDS

Filter Aid	Feed	Run Time (hr)	Plugging Index
HYFLO	Tap Water Only (PI = 37)	0	6
		2	21
		4	21
HYFLO	Tap Water and ASP 400 (PI of water = 37)	0	7
		2	41
		4.5	28
HYFLO	Tap Water and ASP 400 (PI of water = 60)	0	25
		2	65
		4.5	60
HYFLO*	Tap Water and ASP 400 (PI of water = 83)	0	8
		2	>80
HYFLO*	Chlorinated Water and ASP 400 (PI of water = 83)	0	8
		2	68
HYFLO/281A**	Tap Water and ASP 400 (PI of water = 75)	0	2
		2	80

* Double coating (4% $Al(OH)_3$)

** CELITE 281A only double coated.

TABLE 4

HYFLO-CARBON FILTRATION TEST RESULTS

Feed	Run Time (Hours)	PI	Press Drop (psi)
Tap Water (79 PI)	0	33	1.5
and ASP 400	2	30	5.1
	4	29	11.0

When the city water contained less color, as evidenced by lower PI values for the unfiltered tap water, use of DE filter aids coated with aluminum hydrate ($Al(OH)_3$) as precoat and body feed achieved PI values under 40. However, with tap water having high initial PI values when using $Al(OH)_3$, performance of coated filter aids was marginal. For this water supply, it was concluded that HYFLO/PAC mixtures would provide more dependable filtered water quality.

With either option no additional equipment is required. For coated filter aid, supplied premixed to enable formation of the coating at time of use, only a single material would have to be stocked. Obviously both DE and carbon would be needed if mixtures of them are to be used.

Phase II - Ft. Belvoir Filter Tests - Potomac River water is piped directly into the Sanitary Engineering Building at MERADCOM making it a convenient place for a test site. The Potomac at this point is influenced by tidal flows, and previous experience with this supply had shown that it can be a difficult source with both daily and seasonal variations. It still was a difficult water with which to work.

The same skid mounted filter unit that was used at Denver was used at Ft. Belvoir. A small tank, nominally 60 gallons, was obtained from MERADCOM to serve as an unfiltered supply tank and later as a feedwater conditioning tank.

Again, the objective was to attain PI values of 40 or less. Tests were begun in August when the river typically has a heavy concentration of algae, and algae removal was the principle filtration problem. A month later the character of the water had changed and even though turbidity values had doubled, the water was much more easily filtered.

Data for this test period have been compiled in Table 5. The first four runs indicated that some specialized technology would be required to achieve the target levels. Observation of filtered water PI test membranes indicated that algae were not being adequately removed.

Several techniques for controlling algae were available. The best known was pre-chlorination to kill the algae after which they are supposed to be more effectively removed. A number of pre-chlorination runs were made with two of them achieving the desired PI values. One used a double precoat with the second consisting of $Al(OH)_3$-coated HYFLO and PAC and with a similar mixture being fed as bodyfeed. The second run also used a double precoat, the second being untreated HYFLO, with HYFLO and Cat Floc T used as body feed.

Aside from the variety of materials used, these runs had another serious potential problem because the currently specified TFC A300 RO membrane has no tolerance for free chlorine residual. Free Cl_2 may have been completely

TABLE 5

SUMMARY OF FT. BELVOIR FILTRATION TEST RESULTS

Run No.	Pretreatment Type	Pretreatment Dosage ppm	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent (NTU)	Turbidity Filtrate (NTU)	Cycle Length Hours	Pressure PSI	Plugging Index
1			Hyflo	0.15	Hyflo	20			0.8	28	>80
2			Hyflo	0.15	Hyflo	50			2.25	25	>80
3			Coated Hyflo	0.15	Coated Hyflo	75			1	7.5	>80
4	Cl_2	5	Hyflo	0.15	Hyflo	100			2.25	23	>80
5	Cl_2	20	512	0.10	Hyflo	150			5.5	22	64
			Hyflo	0.20	Carbon	150					
			Carbon	0.20							
6	Cl_2	20	512	0.10	Hyflo	150					
			Hyflo	0.20	Carbon	150					
			Carbon	0.20	Cat Floc T	3		0.17	5.75	17	59
7	Cl_2	20	512	0.10	Coated Hyflo	150	13	0.06	6	36.5	30
			Coated Hyflo	0.20	Carbon	150					
			Carbon	0.20							
8	Cl_2	20	512	0.10	Hyflo	150					
			Hyflo	0.20	Cat Floc T	1		0.17	2	5.0	36
			512	0.10	Hyflo	150					
			Hyflo	0.20	Cat Floc T	1		0.17	2	5.5	42
10			Coated Hyflo	0.20	Coated Hyflo	150		0.15	6	34.5	54
11			Hyflo	0.20	Hyflo	150	10	0.5–1.4	2.25	1.5	11
					Cat Floc T	1					
12			512	0.10	Hyflo	150		0.35–0.45	1	0.5	50–77
			Hyflo	0.20	Cat Floc T	1					
13			Hyflo	0.20	Hyflo	150		0.25–1.5	1	2	>80
					Cat Floc T	2.5					
14			Coated Hyflo	0.20	Coated Hyflo	150		0.2	0.5	38.5	39
15			Coated Hyflo	0.20	Coated Hyflo	600		0.1–0.8	2	28	
16			Coated Hyflo	0.20	Coated Hyflo	200	12	0.06–0.5	2.75	35.5	26–45
17	Cl_2	20	Hyflo	0.20	Hyflo	150	15–20	0.31–3.4	24	18.5	
18	Cl_2	20	Hyflo	0.2	Hyflo	150	2	0.1–0.9	21	36	42–47

removed in the run with PAC, but in the run with Cat Floc T there undoubtedly was a substantial free Cl_2 residual which would require neutralization or complete removal.

Three additional runs were made with HYFLO and Cat Floc T without pre-chlorination. One resulted in a PI of 42 but the others were 71 and 50, well above the target level. So further work was concentrated on uncoated and coated filter aids which seemed to have a greater chance for success. Several runs were made with PI values in the 39 to 45 range.

After a review of the data from short term runs, two final long cycles were made. Both used pre-chlorination with about 40 minutes detention prior to filtration. A single HYFLO precoat and HYFLO body feed required about three hours to get the filtered water turbidity down to the MERADCOM-specified 1.0 NTU. Turbidity continued to improve as the cycle progressed, but the poor initial quality would not be suitable for RO feed. The cycle ran for 24 hours with a terminal head loss of 18.5 psi.

By contrast, the second long cycle, using mixtures of HYFLO and PAC (3:1 ratio) for both precoat and body feed,

attained 0.3 NTU level at the first reading. After some upward drift, turbidity values again declined and then stabilized in the 0.1 to 0.3 NTU range. PI values of 42 and 47 were recorded late in the run which lasted 21 hours. Terminal head loss at 38.5 psi was somewhat high, but ten to twelve hour cycles certainly could be projected. Indeed, some reduction in body feed level would still permit ten hour cycles.

Pending modification of the contract to provide for contractor operation of the RO test phases, it was decided that the equipment would be moved to Ft. Detrick in order to keep the program more or less on schedule.

Ft. Detrick Water Treatment Plant - The treatment plant is off-post near the river and supplies potable water to the post. A wet well in the river has a typical arrangement of traveling screen and three raw water pumps with various capacities to handle varying changes in finished water demand. Solution-type chlorinators pre-chlorinate the river water as it leaves the pump house, but there is a sampling line for unchlorinated water which originates between the pump discharge manifold and the

chlorine application point. This sampling line became the source for the DE system.

The DE system was initially located in a MUST unit adjacent to the chlorinator building. The same skid-mounted filter unit used at Denver and Ft. Belvoir just fitted into this "box". A hose was run from the raw water sampling faucet in the chlorinator building to supply the DE system.

In the late fall of 1979 a test series similar to that at Ft. Belvoir was run at this site. The data are summarized in Table 6. At this time of year this supply proved to be relatively stable and easy to clarify.

Work was suspended following these tests until next spring. During spring plowing and periods of heavy runoff, river conditions were entirely different than the previous fall. As a result a new test period to establish operating parameters was undertaken. Results are summarized in Table 7.

TABLE 6

FT. DETRICK FILTRATION TEST RESULTS - FALL 1979

Test No.	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent NTU	Turbidity Filtrate NTU	Cycle Length Hours	Pressure PSI	Plugging Index
1	512*	93	3.1	0.38	2.0	2	
2	512	53	2.2	0.55	3.0	1	
3	512	13.2	2.2	0.35	4.75	20	
4	512**	55	2.2	0.35	3.0	3	
	HOC Carbon	17.6					
5	-	-	2.2	0.45	2.0	25	
6	Coated Hyflo***	50	9.1	1.2	4.0	5	
7	Coated Hyflo	48	4.8	0.45	6.0	10	
	HDC	14.4	+17 Cl_2				
8	512	51	3.2	0.35	2	6	45
	HDC Carbon		+2 Cl_2				
9	512	-	3.1	0.15	<1	40	
	HDC Carbon	-					
	Na Aluminate						
10	Hyflo	-	3.1	0.34	1.3	40	28
	Na Aluminate	-					
	Aluminate	-					

* Celite 512
** Hydro-Darco C, product of ICI Americas
*** 2% $Al(OH)_3$-coated Hyflo

TABLE 7

FT. DETRICK FILTRATION TEST RESULTS - SPRING 1980

Test No.	Body Feed Type	Body Feed Dosage	Turbidity Influent	Turbidity Filtrate	Cycle Length	Pressure	Plugging Index
1	Coated Hyflo	280	70	-	2	28	95
2	Coated Hyflo	192	48	-	3.5	30	57
3	Coated Hyflo	48	12	1	4.7	28	84
4	Coated Hyflo	28	7	1.1	5	25	58
5	Coated Hyflo	40	10	1.0	6	20	71
6	Coated Hyflo	48	12	0.6	5	28	63
7	Coated Hyflo	40	10	1.0	5	20	64
8	Coated Hyflo	128	32	4.0	2	28	-
9	Coated Hyflo	120	20	0.2	6	23	55
10*	Coated Hyflo	84	14	.1-.15	9.5	30	53
11	Coated Hyflo	84	14	.36	10.25	30	54
12	Coated Hyflo	60	10	.34	11.25	30	55
13	Coated Hyflo	48	8	.8	5.5	30	-
14	Coated Hyflo	48	8	.42	3.5	10	63
15	Coated Hyflo	60	10	.14	4.5	22	58
16	Coated Hyflo	60	10	-	4.5	17	-
17	Coated Hyflo	60	10	-	2.0	32	64
18	Coated Hyflo	60	10	-	4.0	32	67
19	Coated Hyflo	72	12	-	3.0	30	61
20	Hyflo	90	15	2.0	4.5	3.75	74
22	Coated Hyflo	60	10	0.15-	6.5	20	63
23	Coated Hyflo	60	10	0.7	5.0	2.2	60

Note: Precoat of Fibra-Cel SW-10 was used at rate of 0.01 lb/ft^2. Also, precoat of Coated Hyflo at the rate of 0.15 lb/ft^2.

* Start of R.O. operation with MERADCOM specified Model 701 PA module.

Not shown in the table are some river water turbidities as high as 600 NTU when only limited operation was attempted. The intent of this test period was to arrive at operating conditions which would provide water suitable for RO feed and such high turbidity levels were not successfully reduced to the arbitrary acceptible level of 0.5 NTU (MERADCOM Spec. 1.0). A maximum PI value was not established for this supply.

A review of the data in Table 7 resulted in selection of $Al(OH)_3$-coated HYFLO for both precoat and body feed. To minimize any potential carrythrough of filter aid fines with the filtered water, an initial precoat of Fibra-Cel® grade SW-10 at the rate of 0.01 pound (4.5g) per square foot of filtering surface was in place before precoating with the coated HYFLO. Use of Fibra-Cel probably could be dispensed with, but in this instance it provided some insurance against unplanned upsets such as power outages and failures in water supply - both of which occurred. A ratio of six mg/l of coated HYFLO to each turbidity unit became standard.

One change which was made was the installation of an intermediate raw water storage tank, one of the G.I. 1500

gallon rubberized collapsible tanks, to cover nighttime periods when smaller river pumps then in service would not provide sufficient volume to the DE system. Toward the end of the RO test period this exposed tank began to cause algae problems but the tests ended before this became serious.

Data compiled in Table 8 cover the DE system operation for the Model smaller 7005 PA period at Ft. Detrick. Table 8 contains data made under two separate circumstances. Shutdown of the filter and the RO unit, dependent on it for filtered water, was controlled by a head loss sensor on the filter influent line. When net filter feed pressure reached 30 psi, a pressure switch shut both units down. The operator normally tried to get in two cycles per day, but under some circumstances made three cycles in an attempt to get more hours on the RO unit. His objective was to complete the 500 hour test period. Reasoning that lower turbidity in the filter feed would lengthen filter cycles so that the RO would get more hours per day, cartridge filters were inserted into the raw water line prior to the conditioning tank to which the body feed was added. This did decrease feed turbidity values 20 to 50

TABLE 8

FT. DETRICK FILTRATION DATA WHEN OPERATING WITH THE RO UNIT*

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage	Turbidity Influent	Turbidity Filtrate	Cycle Length	Pressure	Plugging Index
1	Fibra-Cel SW-10	0.01	Coated Hyflo	84	14	1.0	4.6	32	72
	Coated Hyflo	0.15	"						
2				84	14	0.15	6.1	32	54
3				84	14	0.09	7.1	32	49
4				84	14	0.07	8.0	20	31
5				84	14	0.09	9.0	32	-
6				132	22	0.11	5.0	32	53
7				60	10	0.10	6.5	30	56
8				60	10	0.10	7.0	32	-
9				108	18	0.12	8.0	32	48
10				108	18	0.09	5.5	20	-
11				108	18	0.09	7.5	32	-
12				60	10	0.10	4	12	56
13				60	10	0.12	9.2	32	-
14				360	60	0.40	1.5	22	64
15				168	28	0.40	2.25	32	-
16				150	25	0.16	3.0	32	57
17				120	20	0.20	4.0	26	51
18				120	20	0.18	6.75	32	-
19				120	20	0.09	3.0	34	53
20				108	18	0.12	9.0	32	-
21				108	18	0.15	3.2	32	57
22				150	25	0.14	5.25	32	58
23				150	25	0.15	9.0	30	-
24				150	25	0.11	5.25	28	60
25				60	10	0.12	6.75	32	-
26				60	10	0.14	5.25	25	59
27				90	15	0.15	4.5	32	-
28				90	15	0.16	3.25	32	-
29				120	20	0.09	6.0	32	-
30				90	15	0.11	4.75	30	53
31				108	18	0.10	5.25	25	-
32				108	18	0.10	6.75	32	-
33				108	18	0.07	-	-	-
34				84	14	0.14	8.25	32	58
35				84	14	0.10	11.0	32	-

* R.O. operation with Model 7005A module.

percent and appeared to increase cycle length relative to what would have been obtained for the original water without cartridge filters. However, the cartridges had very short service lives, sometimes only a single cycle, which would make them logistically and economically unattractive.

Of more interest and possible concern in the filtration data presented in Tables 7 and 8 are first, the lack of data on higher turbidity feeds, and second, that while head losses average about 4 psi per hour projecting to 10 hour cycles at 40 psi, the variability was considerably greater than expected or explainable at this point. These were two of the reasons for doing additional work with high turbidities after completion of the final field test.

When work with the smaller RO assembly was started, concentrate and permeate volumes were set in accordance with special instructions by the membrane manufacturer. As shown in Table 9 and Figures 7, 8 and 9, initial rejection was of the order of 97 percent, and a drive pressure about 275 psi was required to obtain 9 percent product from this single element. As operation progressed rejection steadily

decreased and either product volume increased at the same drive pressure, or the latter was decreased to maintain the original product volume. After about 200 hours, rejection was down to about 80 percent and drive pressure had decreased to less than 100 psi. Such a decrease in membrane properties is evidence of damage by free Cl_2.

The probable source of chlorine was found to occur during nights when the plant sand filters were washed. At such times, the river water pumps were shut down, but the Cl_2 solution feeds were left on. Without the dilution of raw water being pumped into the plant, very high concentrations of Cl_2 quickly built up in the lines from which the DE system feed was being taken. Some additional free Cl_2 was carried back to the wet well in the filter wash water. It proved to be impractical to try to change plant operation so Cl_2 would not reach the wet well and agreement was obtained to abandon the test after 202 hours.

TABLE 9

FT. DETRICK R.O. PERFORMANCE

Accumulated Operating Time (Hours)	Feed Pressure (psi)	Feed Flow (gpm)	Water Recovery (%)	Feed TDS (ppm)	Product TDS (ppm)	TDS Rejection (%)
1	275	0.624	9.3	155	5	96.8
7	270	0.645	9.1	156	6	96.1
12	265	0.801	8.0	267.5	7.5	97.2
16	255	-	-	247.5	7.5	97.2
20	255	0.732	9.7	242	7	97.1
24	255	0.686	10.9	242	7	97.1
30	250	0.884	10.3	257.5	7.5	97.1
35	250	0.778	11.4	239	9	96.2
50	220	0.779	10.2	266.5	11.5	95.7
56	230	0.765	11.7	262.5	12.5	95.2
64	200	0.815	10.9	284	14	95.1
72	165	0.739	8.9	277.5	17.5	93.7
80	160	0.748	9.5	278	18	93.5
86	165	0.745	9.2	307	32	91.1
98	145	0.764	10.0	308	33	89.3
103	140	0.746	9.3	319	34	89.3
107	135	0.745	9.3	307	22	92.8
128	150	0.757	9.1	302	22	92.7
132	145	0.758	9.4	320	25	92.2
138	120	0.748	8.8	324	34	89.5
151	120	0.757	9.1	321	44	86.3
154	120	0.758	9.4	333	51	84.7
162	100	0.757	9.1	355	58	83.4
183	100	0.758	9.4	355	65	81.7
202	100	0.759	9.6	360	67	81.4

FIGURE 7

FT DETRICK RO PERFORMANCE

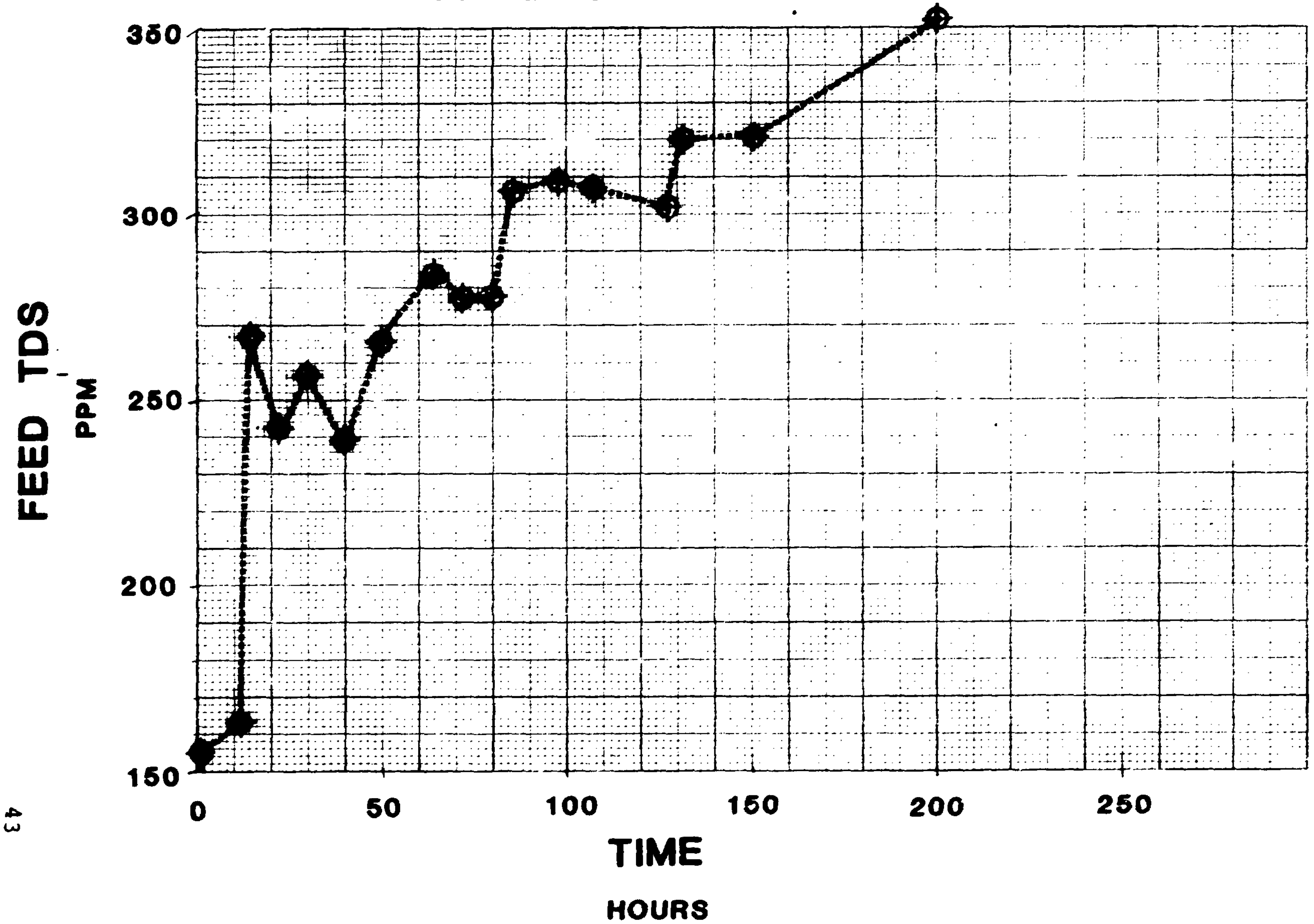


FIGURE 8

FT DETRICK RO PERFORMANCE

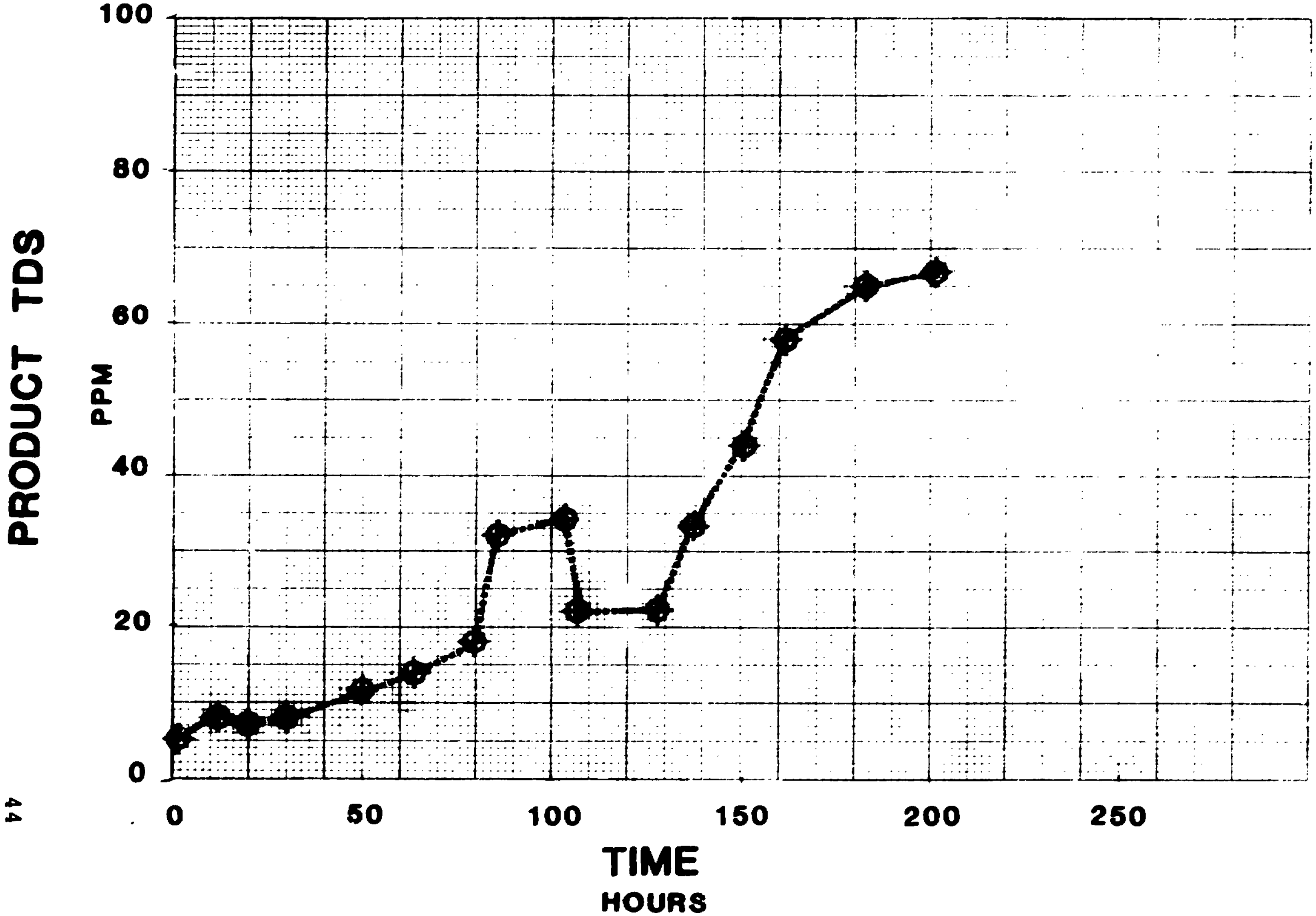
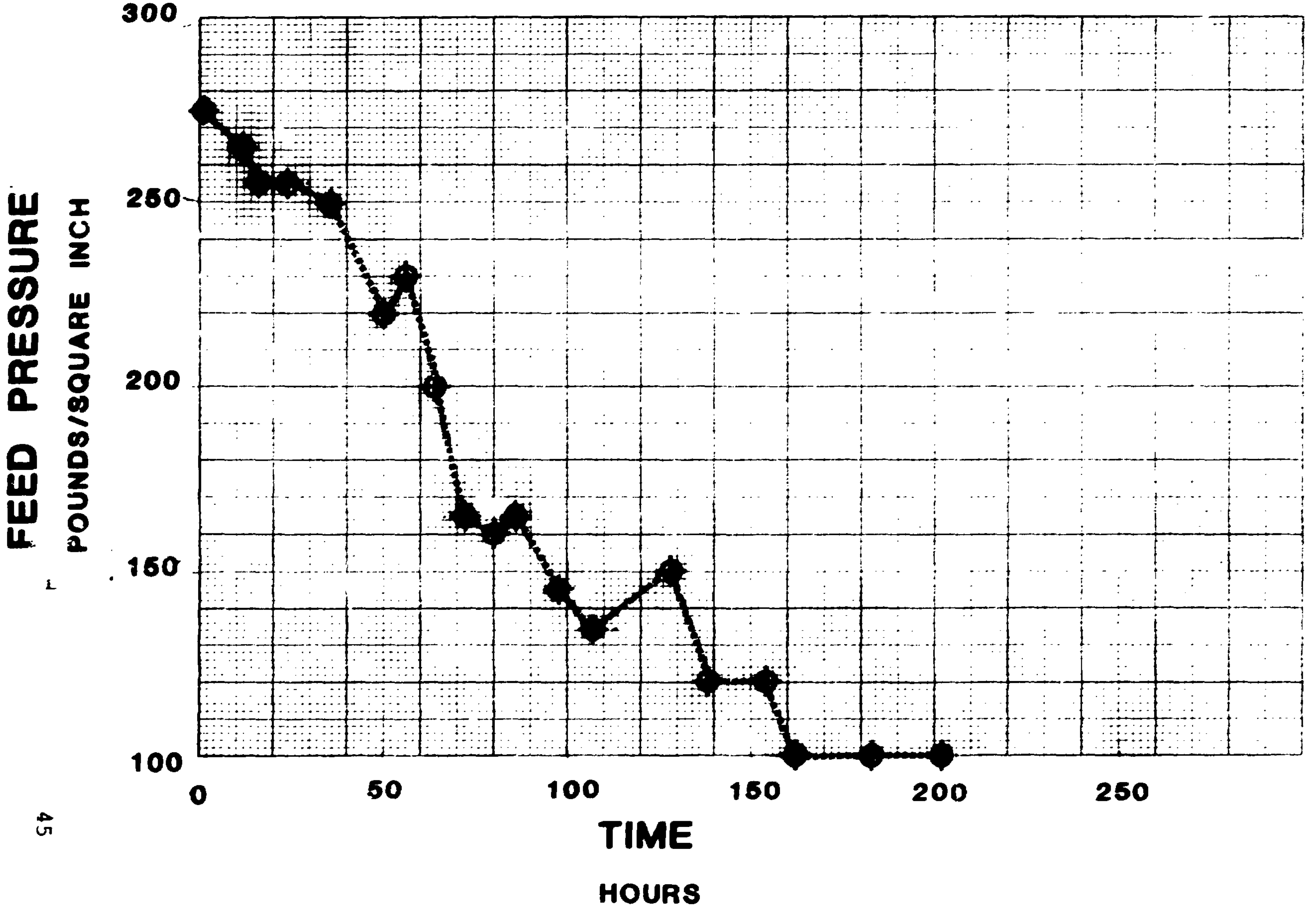


FIGURE 9

FT DETRICK RO PERFORMANCE



At the time the test was terminated there was no evidence of increase in pressure drop through the module which would be indicative membrane fouling or scaling or blocking of the concentrate passages even though flows were in the laminar range instead of the visual turbulent range.

Ft. Eustis Test Site - The two previous sites would require RO treatment for potable water only if some agent other than salinity was to be removed. The Ft. Eustis site was selected as an example of a brackish supply typical of a tidal estuary. Objective of this test was to reduce salinity to potable water levels without fouling the RO module during the 500 hour life test. Since such estuaries often have substantial loadings of suspended organic solids, as this one did, effective filtration is essential. .ecause of corrosion problems in the PI test equipment with this brackish water, turbidity had to be the standard for acceptible quality for RO feed. An arbitrary limit of 0.5 NTU (maximum) was set.

test setup was identical to that at Ft. Detrick. At Ft. Eustis, the precoat also consisted of two filter aids, Fibra-Cel SW-10, a cellulose filter aid and DE. The DE was her coated HYFLO or CELITE 503. The amounts of

precoat added were 0.01 lb. Fibra-Cel SW-10 per square foot of filtering area and 0.15 lb. DE per square foot of filtering area. The precoating rate was 1.5 gallons per square foot per minute (gsfm).

The amount of DE in the body feed slurry was determined by the ratio of body feed required to influent turbidity measured. Before the start of each new cycle, turbidity of the influent stream was measured. Using this turbidity and the body feed rate, the amount of filter aid to be used for the preparation of the body feed was calculated. The body feed was then prepared in the body feed tank and pumped to the conditioning tank at the rate of 50 ml/min.

Influent was obtained using a submersible pump to deliver brackish water from the estuary off the James River to the 1500 gallon rubberized storage tank. The sump pump was placed in a floating stand to avoid pumping mud at low tide. The reason for using the storage tank was to assure that the influent stream maintained a relatively constant turbidity. The brackish water was metered at 1.2 gpm from the storage tank to the conditioning tank. At the inlet

stream to the conditioning tank, body feed was added. The conditioning tank was maintained at half full which gave about a 30 minute conditioning time. After the filter was precoated, the stream from the conditioning tank was opened and a Moyno pump fed influent to the filter. Filtered water went to a 100 gallon tank from which the RO unit received its feed water.

Data for Ft. Eustis are summarized in Tables 10 and 11 and Figures 10 11 and 12. The DE data reflect several conditions. Under initial dry weather conditions, tidal flow may have had more influence on filtering operations than during later wet weather conditions. Some mechanical operating problems due to prolonged wear and tear also affected filter operation. The change from $Al(OH)_3$-coated HYFLO to coated CELITE 503 was made to increase filter cycle length and thereby RO onstream time. The change made no apparent change in DE product quality.

TABLE 10

FT. EUSTIS DE FILTRATION DATA

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent ppm	Turbidity Filtrate ppm	Cycle Length Hours	Pressure psi
1	Hyflo	0.15	Hyflo	40	10	0.41-0.90	-	12
2	Coated Hyflo	0.15	Coated Hyflo	138	23	0.23-0.44	2.75	28
3	Coated Hyflo	0.15	Coated Hyflo	150	25	0.16-0.26	3	31
4	Coated Hyflo	0.15	Coated Hyflo	150	25	0.17-0.25	5	35
5	Coated Hyflo	0.15	Coated Hyflo	150	25	0.25-0.5	2	15
6	Coated Hyflo	0.15	Coated Hyflo	150	25	0.17-0.35	7	35
7	Coated Hyflo	0.15	Coated Hyflo	150	25	0.19-0.20	11.75	35
8	Coated Hyflo	0.15	Coated Hyflo	150	25	0.17-0.30	6	26
9	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	6.25	35
10	Coated Hyflo	0.15	Coated Hyflo	150	25	0.28	6	35
11	Coated Hyflo	0.15	Coated Hyflo	150	25	0.18	5.5	32
12	Coated Hyflo	0.15	Coated Hyflo	150	25	0.19	6.5	35
13	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	6	30
14	Coated Hyflo	0.15	Coated Hyflo	150	25	0.19	6	30
15	Coated Hyflo	0.15	Coated Hyflo	150	25	0.18	6.25	35
16	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5	26
17	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	4	20
18	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	6.25	35
19	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	7.75	35
20	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5	35
21	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20-0.25	6	23
22	Coated Hyflo	0.15	Coated Hyflo	150	25	0.21	1.5	2
23	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	9	8
24	Coated Hyflo	0.15	Coated Hyflo	150	25	0.15-0.18	5.5	27
25	Coated Hyflo	0.15	Coated Hyflo	150	25	0.18	5.5	25
26	Coated Hyflo	0.15	Coated Hyflo	150	25	0.15	9	35
27	Coated Hyflo	0.15	Coated Hyflo	150	25	0.15	5.5	35
28	Coated Hyflo	0.15	Coated Hyflo	150	25	0.16	5	30
29	Coated Hyflo	0.15	Coated Hyflo	150	25	0.18	7	6
30	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	4	30
31	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	3.25	12
32	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	6.5	35
33	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	3	35
34	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5.25	35
35	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5	35
36	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5	35
37	Coated Hyflo	0.15	Coated Hyflo	150	25	0.20	5.5	35
38	Coated Hyflo	0.15	Coated Hyflo	175	25	0.20	5	25
39	Coated Hyflo	0.15	Coated Hyflo	175	25	0.20	5	30
40	Coated Hyflo	0.15	Coated Hyflo	175	25	0.20	6.5	35

TABLE 10 (Continued)

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent ppm	Turbidity Filtrate ppm	Cycle Length Hours	Pressure psi
41	Coated Hyflo	0.15	Coated Hyflo	175	25	0.15	4	8
42	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	5.5	22
43	Coated Hyflo	0.15	Coated Hyflo	175	25	0.18	6.5	35
44	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	5	20
45	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	5	28
46	Coated Hyflo	0.15	Coated Hyflo	175	25	0.15	6.25	35
47	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	3.5	20
48	Coated Hyflo	0.15	Coated Hyflo	175	25	0.15	3	20
49	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	5.5	35
50	Coated Hyflo	0.15	Coated Hyflo	175	25	0.17	5	35
51	Coated Hyflo	0.15	Coated Hyflo	175	25	0.15	5.5	35
52	Coated Hyflo	0.15	Coated Hyflo	175	25	0.16	5.5	35
53	Coated Hyflo	0.15	Coated Hyflo	140	20	0.20	4	35
54	Coated 503	0.15	Coated 503	150	25	0.13-0.18	2.5	35
55	Coated 503	0.15	Coated 503	150	25	0.15	4	35
56	Coated 503	0.15	Coated 503	150	25	0.19	4	35
57	Coated 503	0.15	Coated 503	150	25	0.22	4	35
58	Coated 503	0.15	Coated 503	150	25	0.15	5.5	35
59	Coated 503	0.15	Coated 503	150	25	0.19	3.5	35
60	Coated 503	0.15	Coated 503	150	25	0.24	6.5	35
61	Coated 503	0.15	Coated 503	150	25	0.22	6	20
62	Coated 503	0.15	Coated 503	175	25	0.22	4	35
63	Coated 503	0.15	Coated 503	105	15	0.18	6.5	28
64	Coated 503	0.15	Coated 503	105	15	0.18	14.5	35
65	Coated 503	0.15	Coated 503	280	40	0.18	5.5	30
66	Coated 503	0.15	Coated 503	140	20	0.22	4.5	35
67	Coated 503	0.15	Coated 503	280	40	0.16	2	26
68	Coated 503	0.15	Coated 503	70	10	0.18	6	21
69	Coated 503	0.15	Coated 503	70	10	0.15	10.5	35
70	Coated 503	0.15	Coated 503	140	20	0.15	5.5	35
71	Coated 503	0.15	Coated 503	140	20	0.25	6	35
72	Coated 503	0.15	Coated 503	105	15	0.18	8	35
73	Coated 503	0.15	Coated 503	105	15	0.17	7.5	35
74	Coated 503	0.15	Coated 503	105	15	0.18	8	35
75	Coated 503	0.15	Coated 503	105	15	0.16	8.5	35
76	Coated 503	0.15	Coated 503	105	15	0.16	9.5	35
77	Coated 503	0.15	Coated 503	70	10	0.16	6	30
78	Coated 503	0.15	Coated 503	70	10	0.16	6	35
80	Coated 503	0.15	Coated 503	160	20	0.16	4.5	30
81	Coated 503	0.15	Coated 503	160	20	0.16	4.5	35
82	Coated 503	0.15	Coated 503	160	20	0.20	5.5	35
83	Coated 503	0.15	Coated 503	80	20	0.23	5	35
84	503	0.15	503	160	20	0.33	4	8
85	503	0.15	503	120	20	0.45	13.5	20
86	503	0.15	503	80	20	0.45	7.5	27
87	512	0.15	512	120	20	0.45	5.5	35
88	Hyflo	0.15	Hyflo	160	20	0.35	3.5	6
89	Hyflo	0.15	Hyflo	80	20	0.40	5.5	35

* All precoats contained a pre-precoat of Fibra-Cel SW-10.

TABLE 11

FT. EUSTIS RO DATA

Acc. Operating Time (Hours)	Feed Pressure (psi)	Feed Flow (gpm)	Water Recovery (%)	Feed TDS (ppm)	Product TDS (ppm)	TDS Rejection (%)
2	-	0.78	9.5	14460	460	96.8
4	-	0.76	9.7	15155	355	97.7
8	450	0.79	9.0	16370	370	97.7
13	450	0.76	9.1	15920	320	98.0
18	450	0.78	8.9	11050	250	97.7
23	500	0.78	8.9	11050	250	97.7
48	500	0.78	9.3	10250	250	97.6
68	450	0.78	9.3	10250	250	97.6
86	350	0.78	9.3	11050	250	97.7
101	350	0.78	9.3	10250	250	97.6
114	350	0.83	4.8	11320	320	97.2
120	300	0.83	4.8	11370	370	96.7
136	300	0.84	5.0	11350	350	96.9
155	300	0.83	4.8	10730	330	96.9
165	350	0.83	4.8	10750	350	96.7
177	350	0.83	4.8	11520	320	97.2
190	350	0.83	4.8	10310	310	97.0
197	325	0.83	4.8	10720	320	97.0
213	350	0.83	4.8	10700	300	97.2
230	360	0.83	4.8	10700	300	97.2
234	375	0.83	4.8	11090	290	97.4
245	400	0.83	4.8	11080	280	97.5
262	400	0.83	4.8	10680	280	97.4
275	400	0.83	4.8	10680	280	97.4
295	400	0.83	4.8	10700	300	97.2
301	325	0.83	4.8	9840	240	97.6
310	350	0.83	4.8	10710	310	97.1
313	350	0.83	4.8	11150	350	96.9
330	350	0.83	4.8	11150	340	97.0
335	350	0.83	4.8	10720	320	97.0
356	350	0.83	4.8	10360	350	96.5
366	350	0.83	4.8	10750	300	96.7
385	400	0.83	4.8	9900	290	97.0
405	400	0.83	4.8	9900	280	97.0
439	400	0.83	4.8	10090	280	97.0
451	450	0.83	4.8	9480	280	97.0
488	350	0.83	4.8	9480	280	97.0
502	400	0.83	4.8	9480	280	97.0

FIGURE 10

FT EUSTIS RO PERFORMANCE

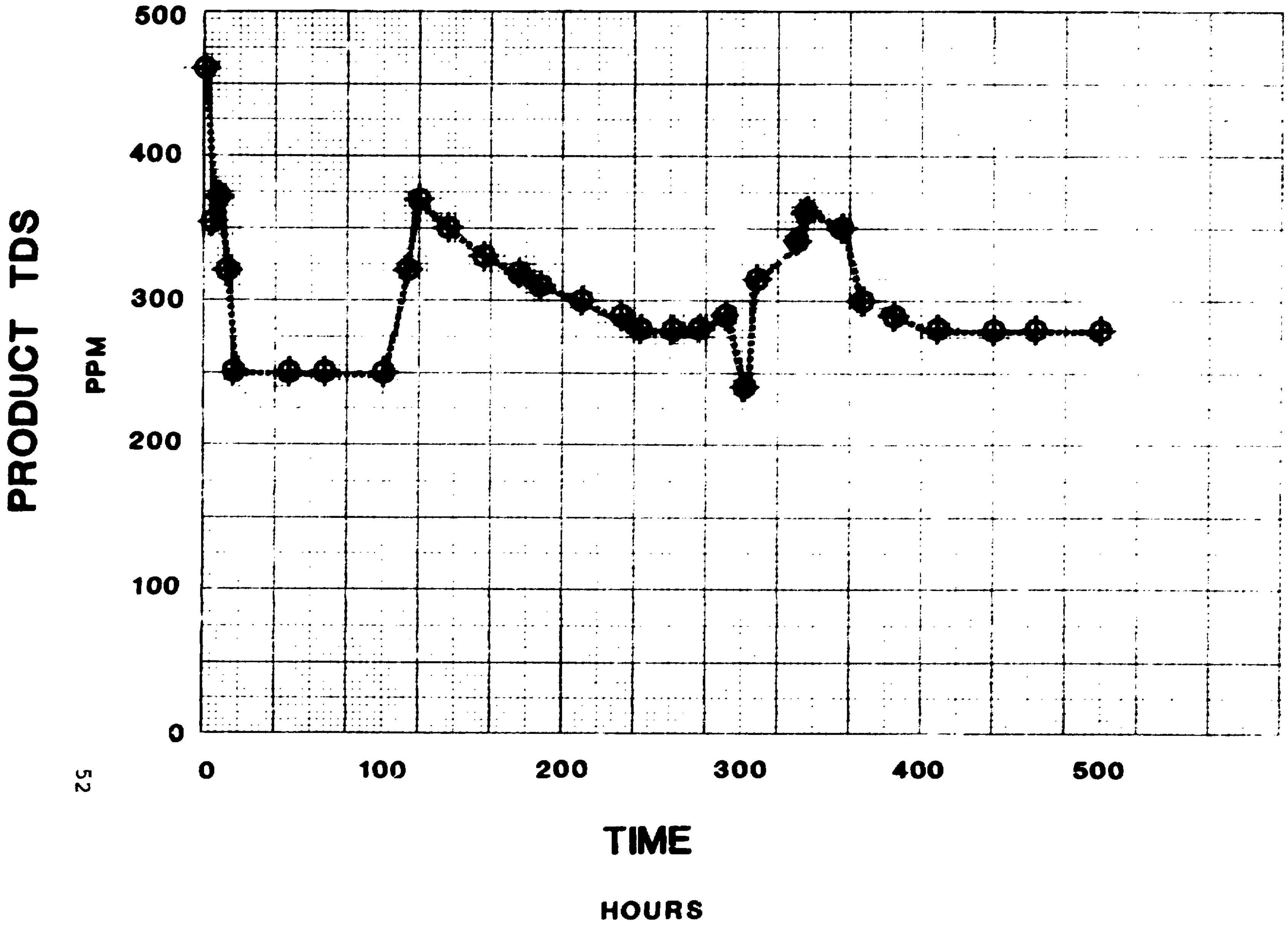


FIGURE 11

FT EUSTIS RO PERFORMANCE

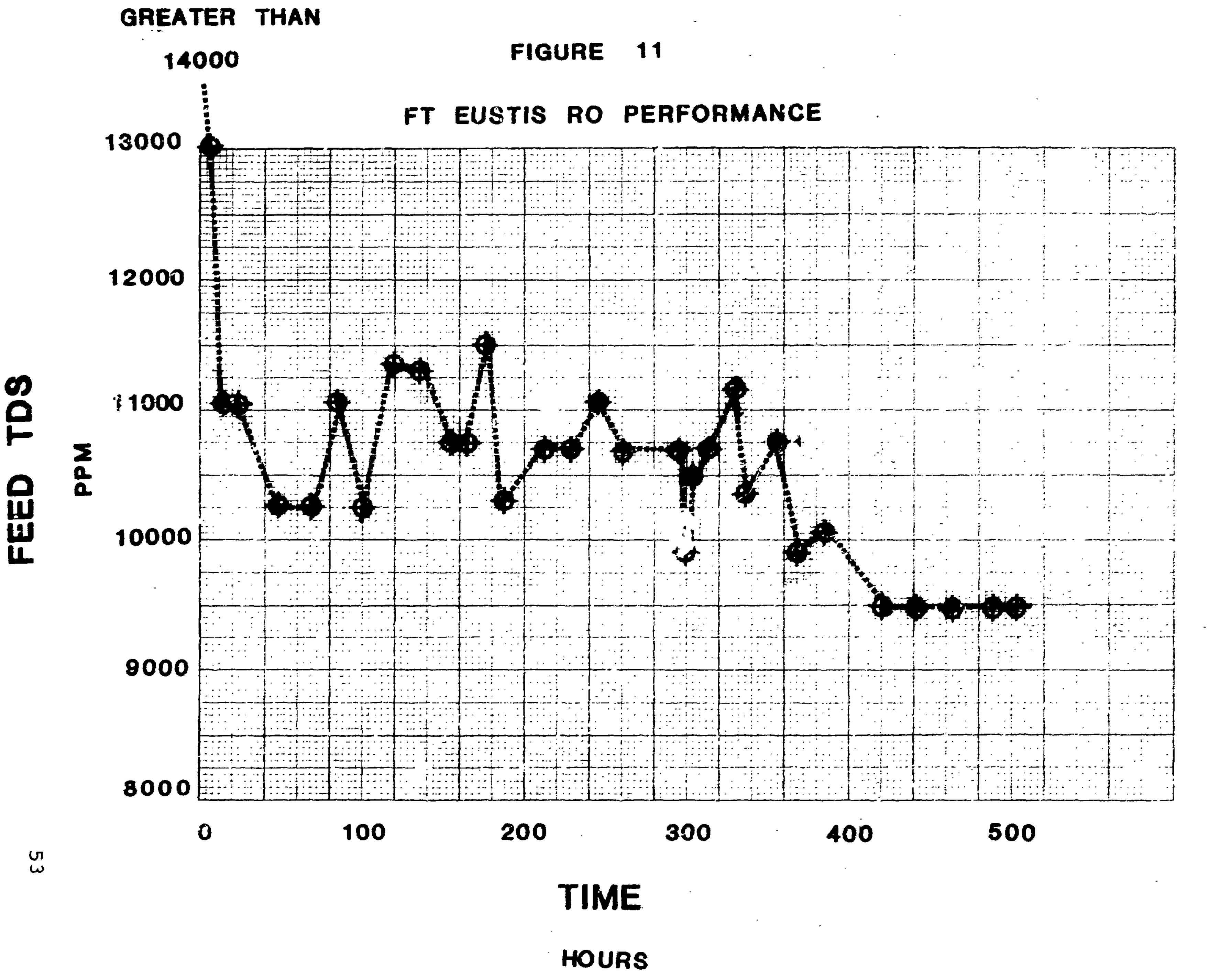
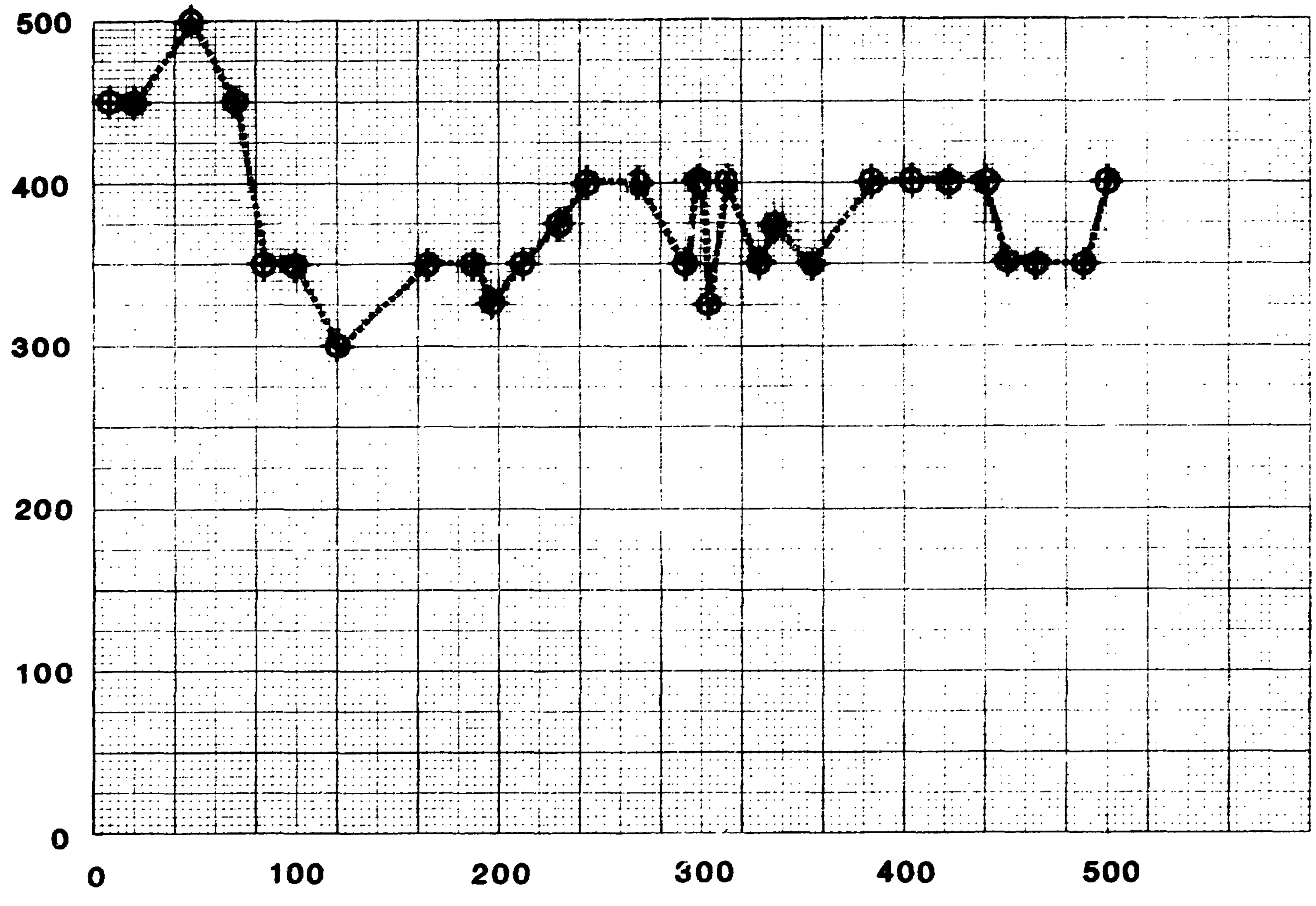


FIGURE 12

FT EUSTIS RO PERFORMANCE



Data from the RO operation showed no changes that could be attributed to membrane fouling or blockage of concentrate channels. The only routine maintenance performed was daily flushing of the module with filtered water at maximum Cat pump output for five minutes without backpressure.

Castle Rock Test Site - Soluble iron (Fe) commonly occurs in both surface and groundwater sources. It is quite common in shallow aquifers and surface waters recharged therefrom in the eastern United States. But it occurs everywhere in the country to some extent. The chemical form of the Fe may vary from one water source to another but is almost always divalent Fe^{++} and tends to precipitate on exposure to air unless special provisions, such as acidification or chelation are taken. Precipitated iron in film form is quite impermeable and would be expected to adversely affect RO operation quite quickly. Removal of the film would require periodic acid cleaning.

Since the 600 gph ROWPU does not have provision for RO feed acidification, the Castle Rock site was selected to demonstrate that soluble Fe can be easily and effectively removed by the same DE system used at the other test sites.

The same equipment used at Ft. Detrick and Ft. Eustis, except for the unfiltered feed storage tank, was used at Castle Rock.

Actual tests were performed at an iron removal plant for a Castle Rock city water well. The equipment was located inside a building which contained greensand filters and the product water pumps. The water for these tests was from the well pump prior to the filters.

Precoat filtration with magnesium oxide (MgO) was used in the removal of iron. In this process, a slurry of filter aid and MgO was pumped through a filter septum which formed a thin precoat on the septum. Then during filtration, the influent was conditioned with a small amount of filter aid and MgO which was continuously added as body feed.

A double precoat was used at this test site but, unlike Ft. Detrick and Ft. Eustis, the first coat was Hyflo and the second was a mixture of Hyflo and light calcined

MgO.* Each precoat was applied to the filter septum by recirculating through the septum in the usual manner at 1.5 gsfm. HYFLO for the initial precoat was 0.10 lbs. per square foot, and for the second precoat 0.5 lbs. of Hyflo and 0.025 lbs. of MgO per square foot were used. Use of the MgO-containing second precoat insured a high degree of initial iron removal.

The body feed was a slurry of HYFLO and MgO with the ratio of filter aid to MgO kept constant at 2:1. The initial body feed rate for HYFLO was set at 10 mg/l 1 of feed and was later reduced to 6.7 mg/l. Using the body feed rate for filter aid, the body feed rate for MgO was determined. Amount of MgO was half that for HYFLO.

Influent was delivered by a well pump that pumped at periodic intervals. The well pump fed to a 100 gallon storage tank. Using a separate pump, the influent was metered from the storage tank to a conditioning tank. at 1.2 gpm.

* Kaiser Refractories, Calcined Magnesia, Grade 10, No. 200.

Because the well pump/iron removal filter system operated on demand from a level controller in an elevated storage tank, the frequency and duration of well pump operation greatly decreased at night. It was necessary to find a large enough feed storage tank and to make system adjustments to hold the pump on long enough to recharge it to cover down periods. Once the storage-recharge problem was overcome, the system ran very smoothly.

Prior to solving these suply problems some poor filter operation resulted from lack of well water. The filter continued to try to operate but most of what was filtered was MgO-containing body feed which would normally constitute a relatively small part of the total volume being filtered. Scaling was observed in he filtered water system as a result of the high pH of the slurry. This probably also occurred in the RO module based on increased drive pressure required to maintain the flow, as shown in Table 12 and Figures 13, 14 and 15.

The scale was found to be readily removed from the filter and filtered water lines by white vinegar after dilution to about one percent acetic acid. This scale was

white, indicating that little or no iron passed the filter. By contrast, all feed water (well water) lines were heavily coated inside with iron oxide.

Next, the RO module was cleaned by recirculating a 1.0 percent solution of reagent grade acetic acid through the Cat pump and housing without backpressure for 7.5 minutes, followed by flushing with filtered feed water until the pH of the flushing water was the same as the filtered feed. This took less than ten minutes, after which the RO system was operated routinely with no further evidence of scaling or increase in drive pressure. There may have been a short term decrease in rejection, but if so it was minimal and the apparent decrease could also have been the result of instrument error.

Once the water supply problem was solved, both DE and RO operations became routine. Features of the DE-iron removal process used are the low filter aid useage and long filtering cycles. As seen in Table 13, one cycle was terminated after 120 hours, not because of head loss but because there was the first indication that Fe slippage was beginning. Other shorter cycles except Run 14 were

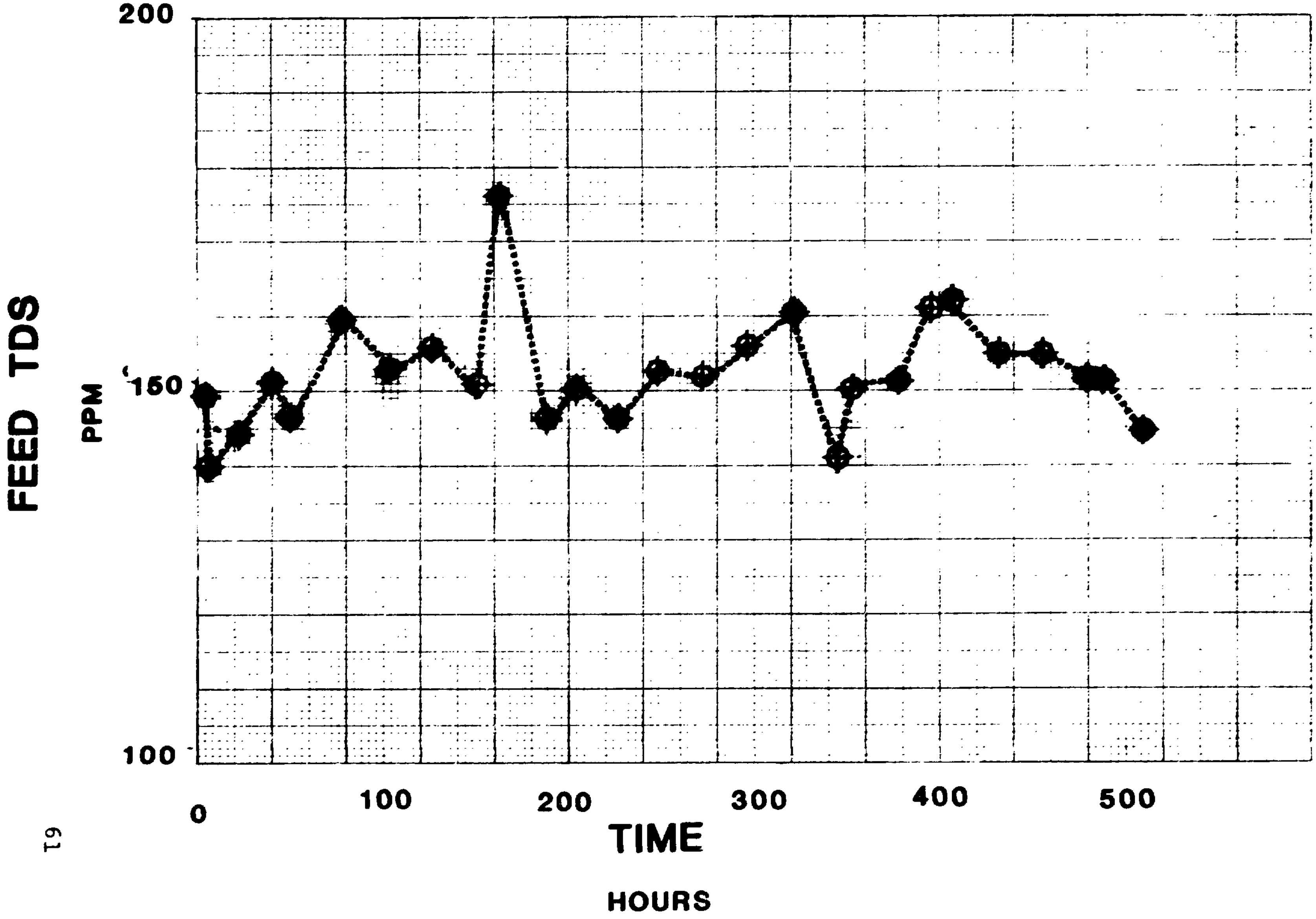
TABLE 12

CASTLE ROCK RO PERFORMANCE

Accum. Operating Time (Hours)	Feed Pressure (psi)	Feed Flow (gpm)	Product Recovery (%)	Feed TDS (ppm)	Product TDS (ppm)	TDS Rejection (%)
4	300	0.832	14.3	149.5	1.5	99.0
6	300	0.872	6.4	140	0.05	99.9
10	300	0.859	6.8	145.5	0.6	99.6
22	320	0.883	5.5	143.6	0.6	99.6
28	390	0.880	6.2	145.9	0.9	99.4
36	300	0.832	6.7	151	1	99.3
40	320	0.844	6.1	151	1	99.3
42	400	0.793	8.3	146.5	1.5	99.0
48	430	0.811	7.8	146.1	1.1	99.2
51	410	0.808	7.4	144.9	0.9	99.4
54	450	0.793	8.3	146.5	1.5	99.0
78	460	-	-	159.2	1.2	99.2
102	450	0.782	7.8	153.2	1.2	99.2
126	450	0.794	7.2	155.8	0.8	99.5
150	470	0.779	7.5	150.9	0.9	99.4
162	460	0.790	7.0	145.9	0.9	99.5
188	480	0.793	7.0	146	1	99.3
202	480	0.836	7.6	150	1	99.3
226	490	0.798	7.1	146	0.9	99.4
248	460	0.789	7.9	152.5	2.5	98.4
272	450	0.806	7.5	152	2	98.7
296	490	0.775	7.0	156.3	1.3	99.2
322	300	0.793	8.3	160.5	2.5	98.4
346	305	0.798	8.9	141.5	1.5	98.9
354	340	0.789	9.6	151.3	1.3	99.1
378	360	0.785	9.1	151.5	1.5	99.0
398	380	0.795	9.3	161.2	1.2	99.3
408	330	0.793	8.3	162.4	2.4	98.5
432	340	0.808	8.4	155.2	1.2	99.2
456	340	0.793	8.3	155.5	1.5	99.2
480	330	0.796	8.6	151.5	1.5	99.0
490	340	0.793	8.3	151.5	1.5	99.0
510	350	0.801	8.3	144.5	1.2	99.2

FIGURE 13

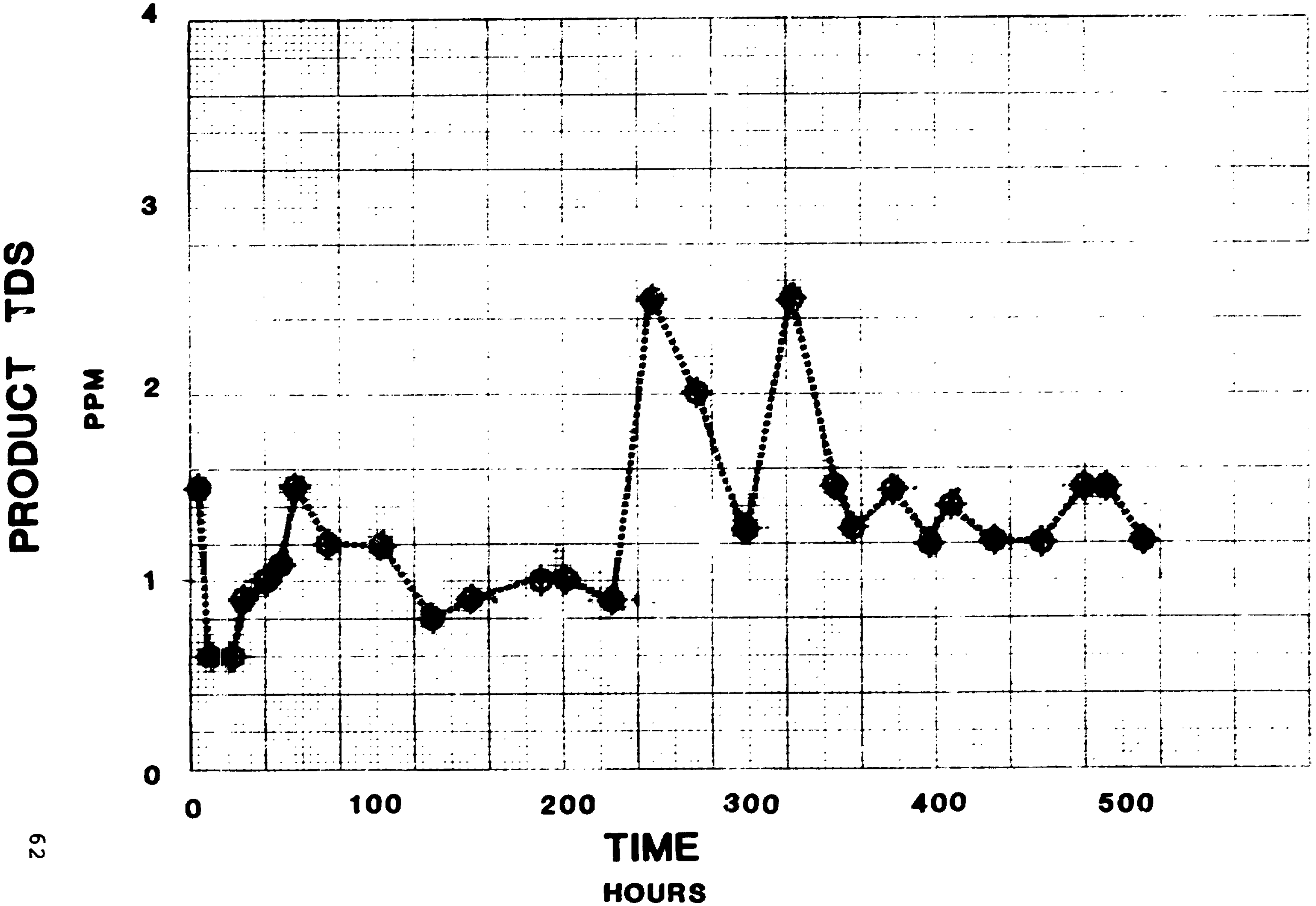
CASTLE ROCK RO PERFORMANCE



NO. 31.395 20 DIVISIONS PER INCH BOTH WAYS. 100 BY 150 DIVISIONS.

FIGURE 14

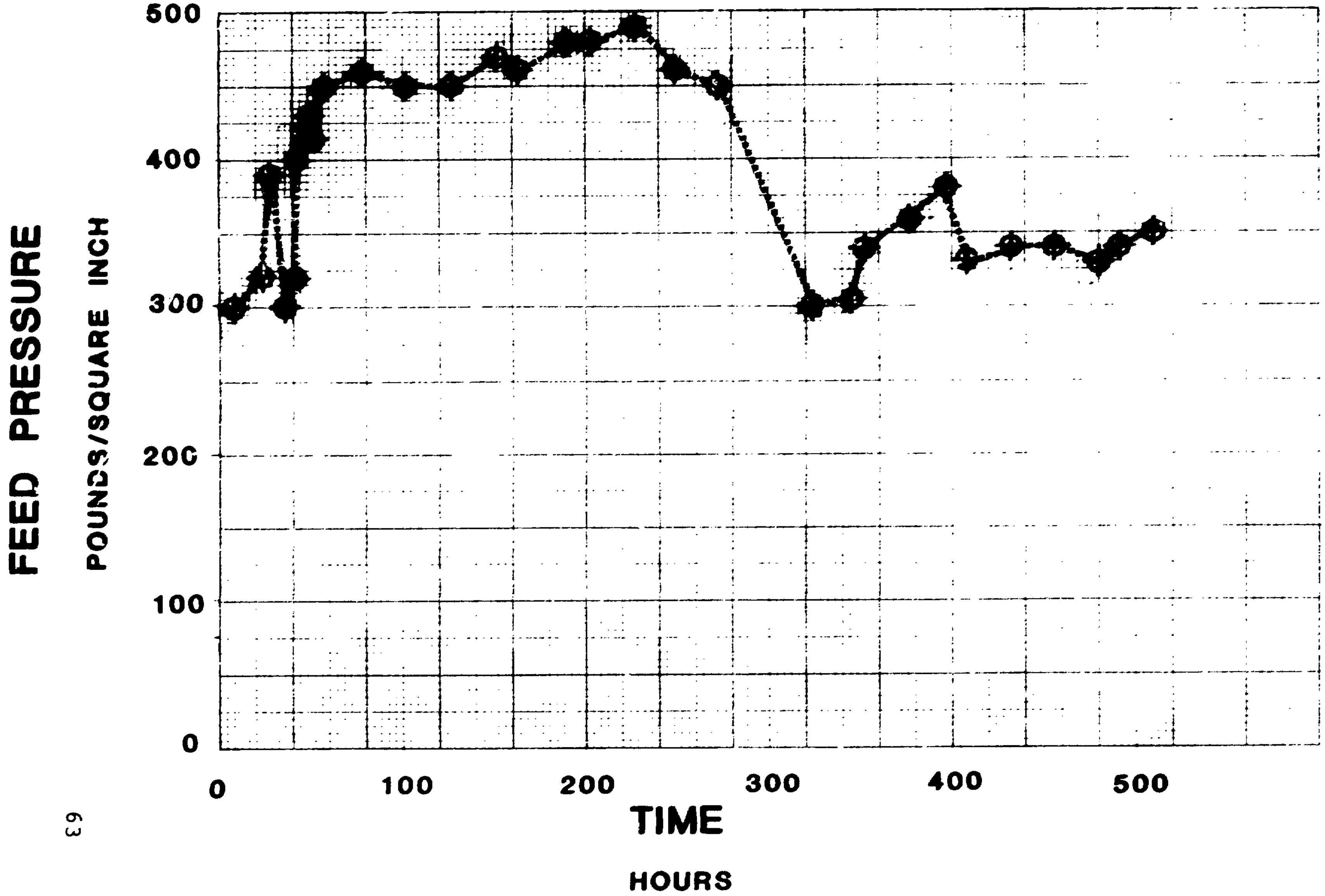
CASTLE ROCK RO PERFORMANCE



NO. 31.395 20 DIVISIONS PER INCH BOTH WAYS. 100 BY 150 DIVISIONS. GRAPH PAPER IN STOCK DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062 PRINTED IN U.S.A.

FIGURE 15

CASTLE ROCK RO PERFORMANCE



terminated for operational convenience or by adverse weather conditions. The unusual head loss during Run 14 was the result of body feed pump failure and demonstrates clearly that while 7.5 mg/l of body feed is not much it makes a big difference in how well the filter operates.

While there was no further evidence of RO scaling or fouling after the cleaning up of scaling due to initial DE/MgO operational problems, comparison of well water and filtered water PI values indicates that the raw well water would have serious fouling potential where the filtered water would have little or none. The data in Table 14 are a comparison of the key chemical constituents of the well and filtered water taken during one of the last runs. The small increase in hardness (as $CaCO_3$) is due to partial solution of MgO, but this process has been used with very hard waters (1,000 mg/l) without scaling problems.

Results from this test site clearly demonstrate that DE filtration will remove Fe where acidification or chelation is not planned.

TABLE 13

CASTLE ROCK FILTRATION DATA

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Iron Concent. Influent ppm	Iron Concent. Filtrate ppm	Cycle Length Hours	Pressure psi	Product Plugging Index
1	Hyflo	0.09	Hyflo	10	1	0.3	6	1.5	-
	Hyflo/MgO	0.09/0.02	MgO	5					
2	Hyflo	0.09	Hyflo	10	1	0.1	4	0.5	-
	Hyflo/MgO	0.06/0.02	MgO	5					
3	Hyflo	0.15	Hyflo	10	1	0.2	-	-	-
			Mgo	5					
4	Hyflo	0.09	Hyflo	10	1	<0.1	9	1	-
	Hyflo/MgO	0.06/0.02	MgO	5					
5	Hyflo/MgO	0.06/0.02	Mgo	5	1	<0.1	14	1	-
6	Hyflo/MgO	0.06/0.02	MgO	5	1	<0.1	17	2.5	-
7	Hyflo/MgO	0.06/0.02	MgO	5	1	<0.1	10	2.5	-
8	Hyflo/MgO	0.06/0.02	MgO	5	1	<0.1	6	0.5	10
9	Hyflo/MgO	0.06/0.02	MgO	5	1	<0.1	11	1.75	-
10	Hyflo	0.09	34 Hr/Hyflo/MgO	10/5	1	<0.1	120	16	17
	Hyflo/MgO	0.06/0.02	86 Hr/Hyflo/MgO	6.7/3.4					
11	Hyflo	0.09	Hyflo/MgO	6.7/3.4	1	<0.1	70.5	18	30
	Hyflo/MgO	0.06/0.02	Hyflo/Mgo	6.7/3.4					
12	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	46	6.5	22
13	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	30.5	28	6.3
14	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	9.5	1	-
15	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	70.5	26.5	25
16	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	95.5	32.5	16
17	Hyflo/MgO	0.06/0.02	Hyflo/MgO	6.7/3.4	1	<0.1	23	4.0	-

TABLE 14

CASTLE ROCK WELL WATER

Key Chemical Constituents

Sample ID	Raw	Filtrate
pH	7.45	7.76
Iron	0.8 ppm	Not Detected
Total Hardness	125 ppm as $CaCO_3$	1[illegible]5 ppm as $CaCO_3$
Total Solid	186 ppm	186 ppm

All tests were run in accordance with "Standard Methods for the Examination of Water and Waste Water" and the Perkin Elmer 403 instruction manual.

<u>High Turbidity Studies</u> - <u>Denver</u> - It was noted in connection with the work at Ft. Detrick that few data were collected relating to high river water turbidities. Since the most difficult operational problems for any direct filtration system, i.e., any system not having coagulation and settling ahead of the filters, probably will occur during periods of high solids loadings, it was felt that more data on high turbidity supplies would make this study more useful. Such a program was set up at Denver.

High turbidity, or more properly high suspended solids data are almost impossible to obtain from a river source because turbidity, solids levels, and solids character change by the hour and sometimes by the minute. Even under laboratory or pilot plant conditions consistant feed quality is difficult to provide if naturally occurring solids sources are used.

For this study, bottom sediments (mud) from a pond which is always turbid were obtained after the pond was drained following a long period of settling. The material which was not allowed to dry, had the texture of axle grease and was about as difficult to wash off or resuspend. After typical dry solids content was determined, a routine for making heavy suspensions was developed. These were then diluted to make a batch of turbid filter feed water. Each batch of 250 gallons supplied feed for up to a four hour filter run.

The high turbidity test water was prepared daily. The mud had a 38 percent moisture content. Preparation of the test turbidity required a slurry of dispersed mud, and the process for making the dispersed slurry was to weigh 315

grams of mud and disperse it in water using a Waring Blender. Dispersed mud was left standing for five minutes and then decanted. The sediment was discarded and the suspended solids were used as the test turbidity. To obtain turbidities of about 200 JTU (Jackson Candle), the test turbidity suspension was diluted with 250 gallons of water.

The equipment used was that shown in Figures 1, 2 and 3. It differed from the original bench test system only by addition of a conditioning tank, and a second reagent pump used when both polymer solution and body feed were pumped.

Three different DE filtration processes were used with the high turbidity water. One process used straight DE filter aid, the second process used aluminum hydroxide coated DE, and the third process used diatomite filter aid with a cationic polyelectrolyte as a conditioning agent. Amount of precoat used in all three processes was 0.15 pound DE per square foot of filtering area. Two different grades of DE, HYFLO and CELITE 503, were used both uncoated and coated with aluminum hydroxide. These same two grades of filter aid were also used as body feed. Body feed levels were in the range of 300 to 450 mg/l.

Before discussing the test results it is important to emphasize a point about the filter feed characteristics. At the beginning of this section a distinction was made between turbidity and suspended solids. This is a significant distinction. By definition in Standard Methods, turbidity is an optical approximation of the amount of particulate material suspended in a liquid, in this case water. Originally, all turbidity readings above 100 and later above 25 were based on the Jackson Candle Turbidimeter. Candle light-extinction values for a diatomaceous earth suspension prepared in a particular way were such that the scale readings (JTU) were, in fact, gravimetric values in mg/l as SiO_2. Over the years a variety of instruments and test suspensions has evolved which have departed from the orginal basis and, unfortunately, have also led to the use of "turbidity" as an absolute measure when such use is not warranted.

The following comparison illustrates the point. The filter feed for the first high turbidity test cycle had the following characteristics:

Turbidity

Jackson Candle	180 JTU
Hach 2100A	85 NTU
Monitek	400 FTU
Gravimetric TSS	2,500 mg/l

Other batches followed the same pattern.

Each turbidimeter was consistant within its own scale, but not to the other turbidimeters in the comparison where high turbidities were being measured. However, for filtered water samples below about 1.0 FTU, Monitek readings consistently were about three times the Hach NTU values.

Over the years since the Jackson was invented in about 1900, it has been surprisingly reliable for high turbidity readings. As there had to be some basis for determining amount of body feed addition, an arbitrary ratio of about two parts DE to one Jackson unit was selected which rounded off to 400 mg/l DE. TSS was not used because most of the DE body feed requirement was associated with the finer particles in the mud, which also have the most influence on turbidity readings, however measured.

Table 15 summarizes data for runs with uncoated and $Al(OH)_3$-coated DE filter aids. Best results were obtained in terms of cycle length and filtered water clarity using 400 mg/l of coated CELITE 503 as body feed. Clarity of the filtered water was adequate for RO feed. Cycle length is projected to about five hours, which seems reasonable for water of this character, and for short term operation when such a source might be encountered. Based on these data, coated DE could meet the required service conditions as set forth in the objectives except for ten hour filtering cycles.

However, contractor personnel in connection with other RO feed water studies recently became aware of work being done by J. F. Pizzino at DTNSRDC, Annapolis, Maryland, involving the use of DE and polyelectrolytes (polymers). Over many years attempts to combine DE filtration with polymer addition or coating have had only limited success - often because there was a specific polymer for each application. The work earlier reported for the Potomac River water at MERADCOM involving Cat FLoc-T appears to fall in this category.

TABLE 15

HIGH TURBIDITY LABORATORY TEST DATA

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent JTU/FTU	Turbidity Filtrate FTU	Cycle Length Hours	Pressure psi	Plugging Index
1	Coated Hyflo	0.15	Coated Hyflo	400	180/394	0.47-0.80	3.5	20	-
2	Coated 503	0.15	Coated 503	400	240/590	0.15-0.19	4.5	28	-
3	Coated 503	0.15	Coated 503	450	240/590	0.17-3.2	2.5	26	60
4	Coated 503	0.15	Coated 503	350	210/520	1.5-3.5	2	15	67
5	Coated Hyflo	0.15	Coated Hyflo	400	270/680	0.38/0.58	2	34	-
6	Coated 503	0.15	Coated 503	400	290/850	2.7-3.5	2	42	82
7	Coated 503	0.15	Coated 503	400	185/410	0.45-0.55	3.5	26	34

Pizzino's work, which has reached the shipboard demonstration stage, involves the use of a DE precoat only and separate continuous addition of a small amount of polymer to clarify relatively clean sea water for RO feed. Without DE body feed, filtering cycles for inshore or harbor water are short. This technology has been adapted to sea water containing up to about 25 mg/l TSS at OWRT's Wrighsville Beach Test Facility (WBTF) by a separate addition of DE body feed after polymer addition. This scheme has been in use for several months and filtering cycles are usually 22 hours long with filtered water quality 35 to 40 PI_{15} and 0.10 or less NTU.

As an exploratory measure, two additional runs on high turbidity feed were made using polymer in roughly the same manner as at WBTF for sea water. Nalco 8100, a cationic polyelectrolyte, was added as a dilute solution to the turbid feed to the conditioning tank (30 minutes detention) where coated body feed normally would be added. Addition was at the arbitrary level of 5 mg/l of the as received polymer. DE body feed was then added at the suction of the filter feed pump. One run used coated CELITE 503 and the second used straight CELITE 503 as precoat and body feed. The same 400 mg/l body feed level that was used without

polymer provides a direct comparison with the prior data. This is shown in Table 16.

These results are of significance. Even though no attempt was made to optimize either polymer dose or body feed level, head loss was substantially lower and filtered water quality as measured by turbidity was better. The potential for reduced body feed alone is sufficient to warrant additional work. Optimization of the polymer usage would appear to have important potential for simplifying field operations. This polymer has been approved by the EPA for potable applications, but is only one of several which have been proposed for use with DE filtration. All such investigations are outside the scope of the present contract.

Costs

Operating Costs - A review of cost elements for operations under field conditions indicates that only DE filter aid represents an appreciable cost variable. Such factors as power and manpower, because of the manner the equipment will be operated, will have relatively little

TABLE 16

HIGH TURBIDITY LABORATORY TEST WITH POLYMER

Test No.	Precoat Type	Precoat Dosage lb/ft^2	Body Feed Type	Body Feed Dosage ppm	Turbidity Influent JTU/FTU	Turbidity Filtrate FTU	Cycle Length Hours	Pressure psi	Plugging Index
1	Coated 503	0.15	Coated 503	400	210/520	0.25-0.38	3	6	21
			Nalco 8100 Polymer	5					
2	503	0.15	503	400	210/520	0.28-0.45	3	3.5	20
			Nalco 8100 Polymer						

effect on costs. Crew size will not change and the principle power requirement is for the RO feed pump. For certain kinds of water sources, e.g., iron bearing, manpower could be substantially reduced - perhaps to one man shift per day, but this would not fit into a standard operating scheme so no savings are claimed for the DE process.

DE does have one advantage over other direct filtration systems, both in terms of cost and required filter capacity. This is due to the small backwash water requirement. So-called dry cake discharge filters are available which have virtually no backwash requirement except to rinse off the leaves prior to the next precoat. Sluicing type filters, similar to the ones used in this study, have very low backwash requirements. An analysis of the Ft. Detrick data shown in Table 17, illustrates this point:

TABLE 17

BACKWASH REQUIREMENTS FOR DE FILTRATION SYSTEM

AT FT. DETRICK

Run No.	Feed Turbidity	Backwash (Percent)	Net Production (Percent)
2	48	1.1	98.9
12	10	0.3	99.7
All Runs (57)	15.4	0.75	99.25

Such small losses require no additional filter capacity to provide backwash water and no real adjustment in filter aid requirements because of the added volume filtered.

So, it is reasoned that the principle operating cost variable to be considered in this study is DE filter aid. DE use and cost, breaks down into two components: (1) the precoat which is amortized over the length of the cycle and hence the volume of filtered water produced (in a fixed rate filtration), and (2) the body feed requirement which is a function of both amount and nature of solids to be removed (filtration resistance) and the desired cycle length, whether attained or not.

In this study, three DE filter aids have been used. The finest, HYFLO, is least expensive costing $175.00 per ton, or 8.75 cents per pound, in standard 50 pound paper bags in carloads f.o.b. factory.* CELITE 503 on the same basis costs $197.00 per ton, which rounds to 10 cents per pound. A mixture of CELITE 503 and appropriate amounts of chemicals from which $Al(OH)_3$-coated DE can be prepared (simply by adding to water and stirring) has been produced in the past but is not currently in production. This material produced in reasonable quantity is estimated to cost $300.00 per ton or 15 cents per pound f.o.b. factory. The big advantages of the mixture are the simplicity of preparation and the need to stock only one material.

The above prices, since no packaging or shipping instructions have been specified, do not include special export packaging if required, or distribution to warehousing locations.

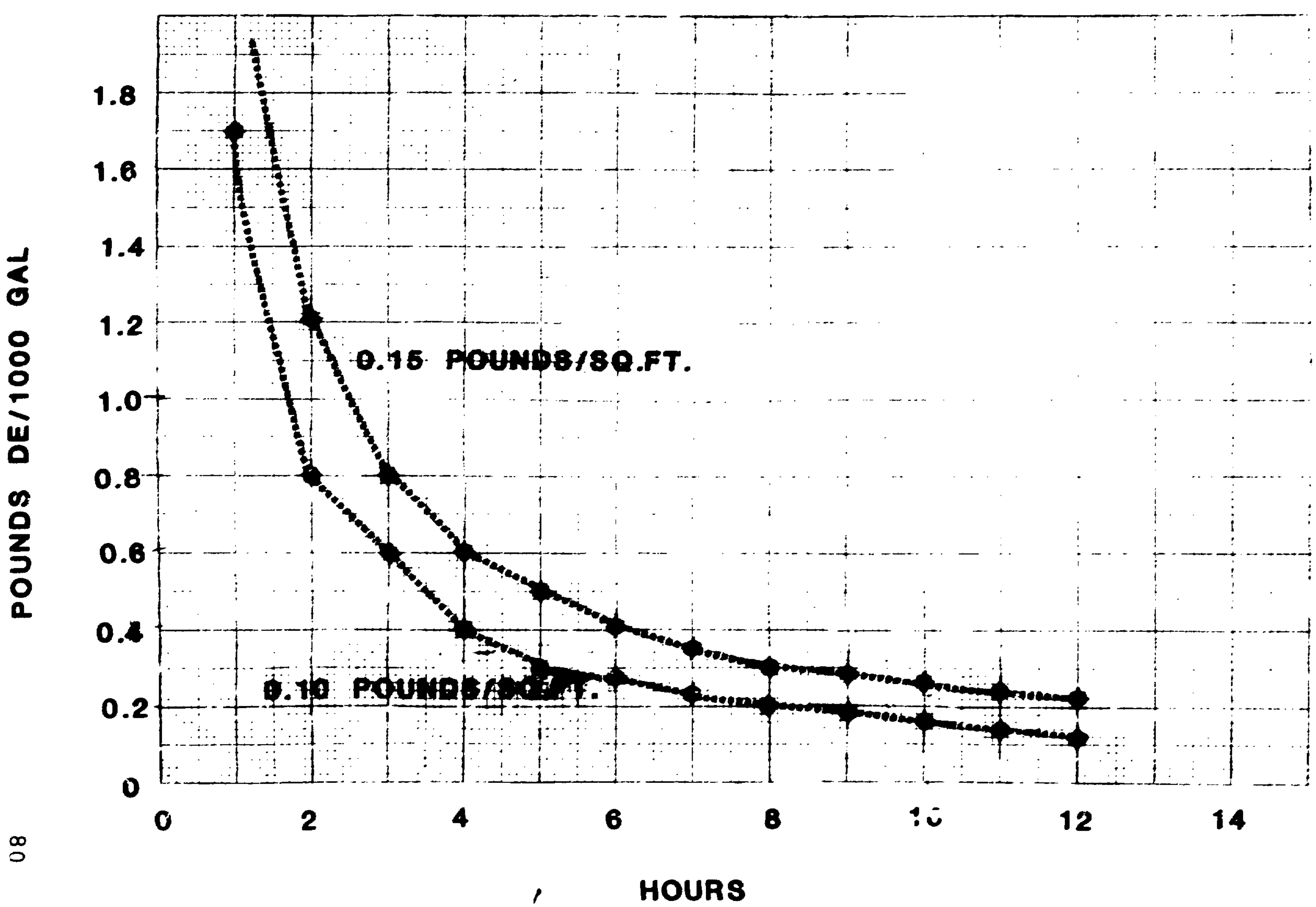
* All prices are as of June 1981

As noted, one of the DE cost elements is for precoating. Figure 16 shows how precoat use is tied to filter cycle length. The usage shown is for a 30 square foot filter which would supply a 600 GPH ROWPU. Two levels of precoat usage are shown, 0.10 and 0.15 lb. per square foot. For most of the work in this study, the higher figure was used but most large scale applications are based on the 0.10 pound level. This same information has been costed out for the three filter aids at the 0.10 lb. per square foot level in Table 18. In Figure 16 it can be seen that precoat cost decreses rapidly to about five hours but becomes much less of a factor thereafter. This becomes even more apparent when looking at the costs in Table 18.

On the other hand, body feed amount and cost, assuming uniform water quality of the feed, is a constant related to the filtration resistance of a specific water source. Table 18 gives the estimated filter aid costs for various body feed levels for the three types of DE noted earlier. Low levels of body feed are relatively inexpensive and high levels are expensive.

FIGURE 16

PRECOAT USE OF DE FOR A 600 GPH ROWPU



Total DE filter aid cost, then, is the sum of the precoat and body feed costs per thousand gallons filtered. Using the coated CELITE 503 figures, a ten hour cycle with 50 mg/l body feed would have a DE, cost of 8.9 cents per 1000 gallons. At 100 mg/l body feed this would increase to 15.1 cents. Costs of filtering very turbid or high TSS water will be expensive, of the order of 55.0 cents per 1000 gallons assuming 5 hour cycle length and 400 mg/l body feed, but the essential point is that when such a supply is encountered it can be successfully filtered to provide water suitable for RO feed.

While this study was not directly concerned with the polymer-DE system noted in the preceeding section, the potential cost savings of such a combination can be pointed out. The unoptimized cost of the polymer as run was 4.2 cents per 1000 gallons and based on a rate of head loss increase (dp/dt) it appeared that about 200 mg/l of CELITE 503 might suffice as body feed to achieve a 10 hour cycle length for a total DE cost of 18.4 cents. The combined cost of DE and polymer, 22.6 cents, is only about 40 percent of the cost of coated-CELITE 503 to do the same job.

TABLE 18

DE PRECOAT COST FOR A 30 SQ FT FILTER OPERATING AT 30 GPM

Filter Cycle Length (Hour)	Wt. of Precoat (Lb.)	Vol. Filtered/ Hr. (Gal.)	Cost of DE/ 1000/Gal. Filtered	Filter Aid Precoat Cost/1000 Gal.		
				Hyflo (@ 8.75¢)	Celite 503 (10.0¢)	Celite 503 Mix (15.0¢)
1	3.0	1,800	1.67	14.6	16.7	25.0
2	3.0	3,600	.83	7.3	8.3	12.4
3	3.0	5,400	.56	4.9	5.6	8.4
4	3.0	7,200	.42	3.7	4.2	6.3
5	3.0	9,000	.33	2.9	3.3	5.0
6	3.0	10,800	.28	2.5	2.8	4.2
7	3.0	12,600	.24	2.1	2.4	3.6
8	3.0	14,400	.21	1.8	2.1	3.2
9	3.0	16,200	.19	1.7	1.9	2.9
10	3.0	18,000	.17	1.5	1.7	2.6
11	3.0	19,800	.15	1.3	1.5	2.3
12	3.0	21,600	.14	1.2	1.4	2.1

TABLE 19

DE BODY FEED COSTS AS A FUNCTION OF BODY FEED LEVELS

Body Feed Level (mg/l)	10	25	50	75	100	200	400
Grams/ k gal.	37.8	94.6	189.2	283.7	378.3	756.6	1,513.2
lbs/k gal.	.08	.21	.42	.62	.83	1.67	3.33
Body Feed Cost/ k Gal.							
Hyflo @ 8.75¢ /lb.	0.7	1.8	3.7	5.4	7.3	14.6	29.1
Celite 503 @ 10.0¢	0.8	2.1	4.2	6.2	8.3	16.7	33.3
Celite 503 Mixture @ 15.0¢	1.2	3.2	6.3	9.3	12.5	25.0	50.0

Equipment Costs - The following section covers generally some sources of equipment which will fit into the available space. Potential vendors were asked for budget pricing of "packages", i.e., pumps, tanks, valves and flow meters as well as filters, to arrive at an outside range of estimates. These prices ranged between $10,000 and $38,000 depending on type of filter, materials of construction and specific accessories. Additional research could probably broaden the range still more. As one example, the Blace filter being considered by the Navy for shipboard use is simpler and less expensive, but is not now made with enough filter area to serve the 600 GPH ROWPU. Possibly the Blace filter could be made large enough if there was enough demand.

Comparison costs for a substitute DE system and the present multi-media filter system is not feasible under the circumstances. Selection of a particular DE configuration and availability of costs of the present system are needed to make such a comparison possible.

Availability and Fit of Hardware

A key question, since the 600 GPH ROWPU is a design already "on the street", is whether DE filter equipment can

be fitted into the space occupied by th multi-media filter components. Since total redesign is now impractical, any change should be limited to the same space with possible minor rearrangement of some RO auxiliaries if necessary.

Drawings of the unit furnished to the contractor by MERADCOM show that a gross space of about 60 inches long by 42 inches wide and 58 inches high must contain the filter, its accessories and such off platform components as auxiliary tanks (collapsible), etc., normally transported with the unit. The above dimensions do not outline a regular geometric figure.

Of about a dozen domestic DE filter manufacturers, three known to have equipment which might fit the space were contacted. These were:

The Durion Company, Maryland Heights, Missouri
Industrial Filter & Pump Co., Cicero, Illinois
United States Filter Corp., Whittier, California

Each of the above provided data on a variety of filter configurations and each can provide equipment which will fit into the available space. In some cases minor

modification, e.g., shortening of legs, would be required. A more difficult decision, not made here, is whether the filter selected should be of the "dry cake" discharge type or the sluicing type. This decision would be governed in part by how the cake is to be disposed of.

In all cases, a 500 gallon rubberized tank and submersible pump for stirring have been included for an off-platform conditioning tank for the unfiltered water. This tank would be used for either coated filter aid or the polymer-DE system if that proves to be feasible.

Since the existing design includes a polymer feed system, change to coated DE would involve only a change in tank configuration and probably a different metering pump. This assumes purchase of premixed DE. Space for a limited amount of DE would be included.

Funding for detailed design of a modification was not included in the contract. Enough background work has been done to establish to a reasonable degree that the availble components can be fitted into the available space and that

design work directed toward modification would be warranted. However, this should be after process selection and backwashing mode have been finalized.

CONCLUSIONS

Results of these studies lead to the following conclusions:

1. DE filtration is capable of providing water suitable for RO feed from a wide variety of sources, suitability being defined in the objectives as 0.5 NTU versus the Army specified 1.0 NTU, and a 30 psi PI_{15} value of 60, where the latter could be measured.

2. Of the various DE filter aids used $Al(OH)_3$ coated filter aids, and more specifically coated CELITE 503, were the most effective. An exception was the DE-MgO Fe removal study where a coated filter aid was not required but would not be adversely affected by its use.

3. DE was the major operating cost variable and it was found to be a function of the nature of source contamination to be removed. Observed DE costs ranged from less than 4.0 cents to 55 cents per 1000 gallons filtered.

4. Of the two 500 hour RO life tests completed, neither had any adverse effects due to particulates in the filtered water. One test did have chemical scaling due to adverse filter operating conditions but this was easily corrected and no further problems were encountered.

5. DE filter equipment is available which can be fitted into the space now occupied by the multi-media filter and accessories in the 600 GPH ROWPU. Modification of the2000/3000 GPH ROWPU would be even easier.

6. Equipment cost comparisons cannot be made until certain decisions relating to a more specific DE filter selection have been made. These decisions require some detailed engineering outside of the scope of these studies.

7. Use of new polyelectrolyte-DE combinations, not known to be available when the project was initiated, appear to have important advantages for very turbid waters, based on very limited tests. Data from other work in progress indicates applicability to less turbid waters also.

RECOMMENDATIONS

Recommendations arising out of this study are as follows:

1. That DE filtration has the capability to provide adequately clarified water for RO feed, and therefore should be seriously considered as an alternate for the presently specified multi-media filter.

2. Based on the results of these studies, that DE premixed to form $Al(OH)_3$-coated DE when mixed with water be specified as the DE grade of choice. Such a mixture is simple to use since the directions are "add water and stir", and only one material would be stocked. The DE grade should be equivalent to Celite 503.

3. Additional work with polyelectrolyte-DE systems should be authorized to determine the scope of applicability and potential cost savings over the use of DE and coated DE for a variety of water sources. Based on the experience gained in these

studies actual RO service tests probably would not be needed.

4. Sufficient engineering design work, which would include certain key DE equipment decisions, should be authorized to determine what changes in the 600 GPH ROWPU component locations might be required. It is believed that these would be minor, but until a backwashing mode and filter conforming thereto are selected the extent of change, if any, cannot detailed.

APPENDIX 1

PLUGGING INDEX TEST PROCEDURE

Originally developed as a measure of the suitability of water for injection for secondary recovery of oil, this flow decay test has since been refined for a variety of uses. It became a practical reality with the development of filter membranes. The test method described in this appendix generally follows the adaptation suggested by Polymetrics as a means of judging suitability of feedwater quality for RO applications.

Test Method - Figure 1-A shows a schematic of the PI test setup and Figure 2-A is a photograph of the test being run. Enough filtrate was collected to fill a six gallon pressure tank. Air at 30 psi was applied to the tank. A stainless steel membrane filter holder (47 mm) was attached to the tank. A 0.45 um membrane filter was placed in the holder and while the cover was loose, water was let in to void the air above the membrane. The holder was tightened and a graduated cylinder (1000 ml) with the 500 ml mark accented with black marker was placed underneath. The flow valve was opened and the collection of 500 ml was timed in

seconds (T_0*). The flow valve was kept oper for 15 minutes. Every 5 minutes a 500 ml sample was timed.

(T_5*, T_{10} *, T_{15} *) until 15 minutes had elapsed. The 15 minute plugging index was calculated as follows:

$$PI^*15 = \left(1 - \frac{T_0^*}{T_{15}^*}\right) \times 100^*$$

Five minute and fifteen minute plugging indices are calculated in the same way and are used with poor quality waters.

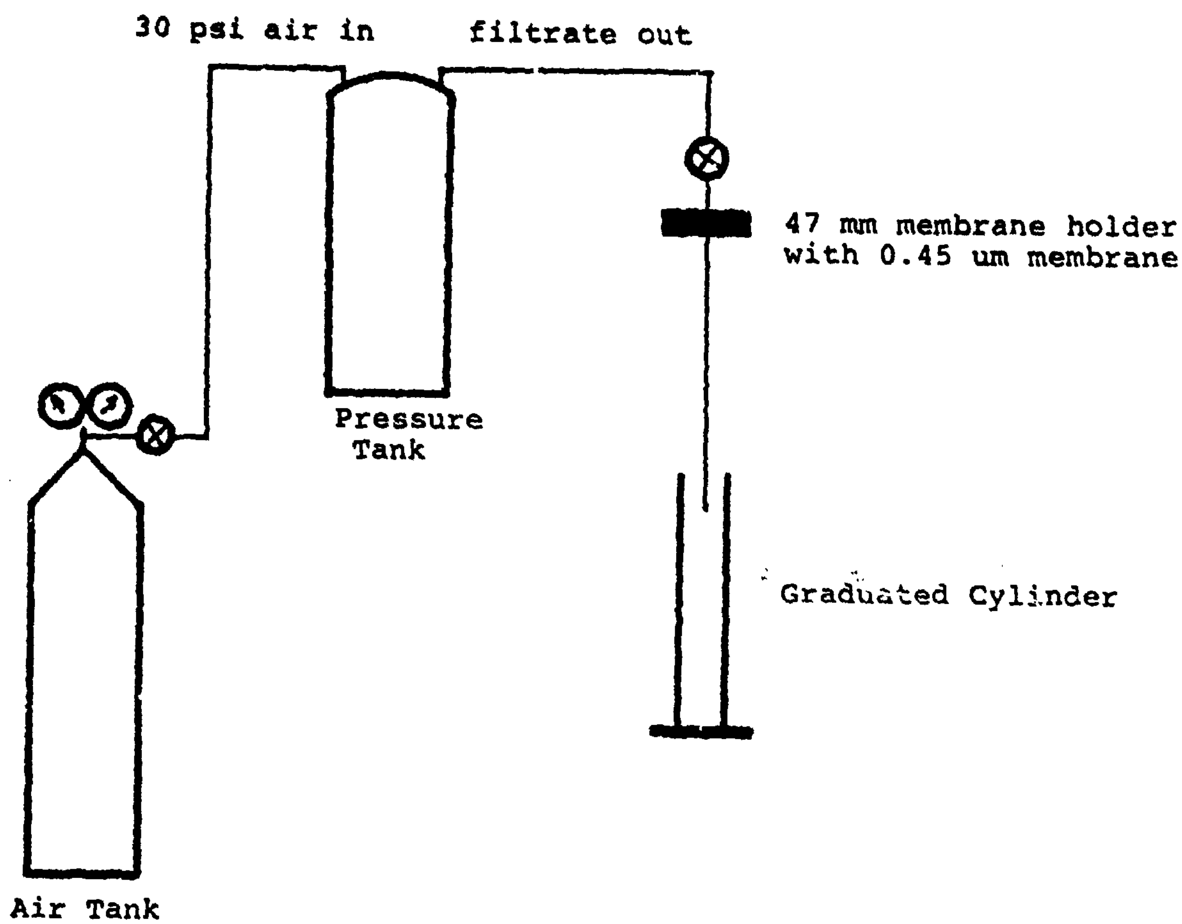


FIGURE 1-A. Plugging index test setup.

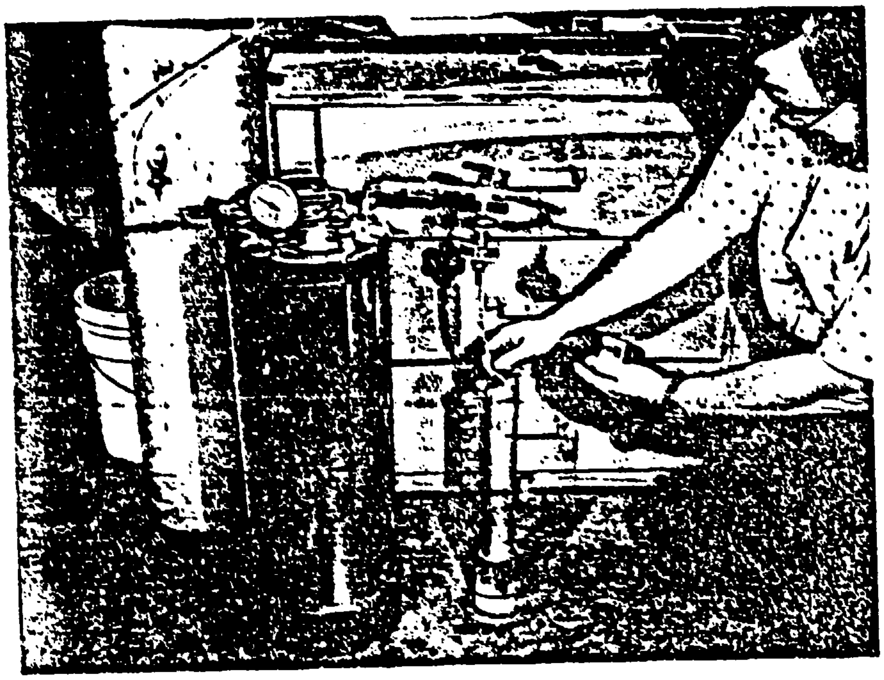


FIGURE 2-A. Plugging index test being run.